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| **Project title** | Nutrient Requirements for Field Grown Herbs. |
| **Project number:** | FV 359 |
| **Project leaders:** | Prof Ralph Noble<br>Dr Debbie Fuller, Warwick HRI |
| **Report:** | Final, March 2011 |
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| **Key words:** | Coriander, Mint, Nitrogen Fertiliser |

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# GROWER SUMMARY

## Headline

- Yields and shelf-life of coriander and mint are influenced by the availability of nitrogen (N). Data to support growers in the application of suitable rates of N has been generated.

## Background and expected deliverables

At an estimated total value of £77 Million in the UK, herbs form a significant sector of the market and yet there is little specific information to support the industry in producing herb crops. In particular, this project focussed on the nutrient requirements of field grown herbs and, given the wide range of both species and mineral elements relevant to this question, addressed specific issues.

Firstly, since UK herb production is largely focussed towards fresh weight yield, nitrogen was chosen as the key element to investigate. Applying correct levels of nitrogen was expected to produce the biggest gains in terms of fresh weight yield, yet it is also a mobile element that causes diffuse pollution when used in excess. Establishing suitable rates of N is expected to improve productivity whilst minimising waste and pollution. Secondly, two species were chosen for the investigation based on their prominence in the UK market and their cropping patterns. Coriander was chosen as an annual type with a single harvest and mint was chosen as a perennial with a more complex repeat harvest requirement as well as a longer term production period (typically up to 5 years, although this project examined the first two years of production).

Whilst the commercial aim of maximising yield is important, growers of fresh herbs are also concerned that they do not compromise product quality and hence evaluation of N availability on product shelf life formed an integral part of the assessments carried out. As coriander is particularly susceptible to problems with shelf life, additional treatments were included in the project to assess the potential for extending post harvest longevity. The treatments followed from observations made in a previous HDC funded project (PC 259) where adding salt to a hydroponic feed solution improved shelf life. Given the potential for salt to impair soil quality in the longer term the use of extra K on plots was assessed as an element that may equally increase osmotic pressure on the plant prior to harvesting

The project was therefore designed to:-

- Produce data regarding the N requirements of coriander and mint grown in UK conditions which will be of direct use for UK commercial production.
- Determine how N fertiliser rate may impact on shelf life of fresh bunches of coriander and mint.
- Evaluate the potential for enhancing coriander shelf life through the use of K top dressing.

Since shoot tissue analysis formed a significant component of the work, summaries of nutrient status of a wider range of elements beyond nitrogen were also generated and summarized as a supplementary reference source.

Values for nitrogen (N) in this report refer to elemental N rather than nitrates. Yields quoted are for individual crops (coriander) or for sequential cuts from a single crop (mint).

## Summary of the project and main conclusions

- Data was generated to support growers in the application of suitable rates of N to field grown coriander and mint. Yields of coriander and mint were clearly influenced by availability of N, and data from the trials was used to generate provisional recommendations for N fertiliser applications. These now need to be tested on a wider range of sites and in different years.
- Leaf greenness of coriander and mint were improved by N applications, but there were no further increases in greenness at levels of available N above 131-172 kg/ha.
- Wilting was the main factor determining the shelf life of coriander; samples grown without N application wilted most slowly but these had poor leaf colour quality. Where N was applied at 60 kg/ha or more, differences in wilting between N rates were small or not statistically significant.

- Browning/ necrosis was the main factor determining the shelf life of mint. At the first cut of the second season, samples grown on plots with 51-78 kg/ha available N had a longer shelf life than samples grown on plots with lower or higher levels of available N; in the second and third cuts, shelf life decreased with increasing availability of N.

**Coriander – yield**

Response of coriander to six levels of N (from 0 to 300 kg/ha N applied) was assessed in randomised plots at Warwick University, Wellesbourne on crops drilled in May, July and August 2009. Application was split as one third as a base dressing and two thirds as a top dressing. In separate trials at Valley Produce, all of the N was applied as a top dressing. Estimates of yield were made by sampling each crop on three occasions (i.e. two interim samples and a final harvest sample). The level of applied N associated with the highest yield varied with drilling date and also, to some extent, time of sampling. Table A indicates the N treatment producing maximum fresh and dry weight yield for each sample from the Wellesbourne trials, together with the final fresh weight yield for the most productive N treatment for each trial. Since the N available to the crop is a combination of that available from the fertiliser applied and that already available in the soil, the table includes a figure for available N to 30cm depth. This is calculated from the mineral N analyses carried out on soil samples prior to drilling each trial plus the amount of N applied as the treatment.

**Table A**. *N treatments producing the maximum fresh and dry weight coriander yields from the Wellesbourne trials.*

| Rate of applied (and available) N producing maximum yield (kg/ha) | Drilling Date | | |
|---|---|---|---|
| | 21/05/09 | 23/07/09 | 11/08/09 |
| Interim sample 1 | 300 (325) | 160 (204) | 60 (81) |
| Interim sample 2 | 300 (325) | 110 (154) | 60 (81) |
| Final sample | 230 (255) | 110 (154) | 60 (81) |
| Yield (t/ha Fwt) from the best N treatment* | 47.8 | 15.6 | 26.0 |

**The lowest N application treatment above which no further significant increases in yield were obtained.*

Trials at the commercial site (Valley Produce) considered 5 rates of N (from 0 to 276 kg/ha) on plots drilled in June and August 2009. These trials were less responsive to the rate of N applied but background N levels also differed. These data provide a benchmark for the Wellesbourne trials, and while response to applied N varied between the two sites, reasonable agreement is found if calculated available N levels (to 30cm depth) generating maximum yield are compared; as can be seen from the Table B.

**Table B.** *Treatments producing the maximum fresh and dry weight coriander yields from the Valley Produce trials.*

| Rate of applied (and available) N producing maximum yield (kg/ha) | Drilling Date | |
|---|---|---|
| | 17/06/09 | 11/08/09 |
| Interim sample | 60 (293) | 60 (131) |
| Final sample | 60 (293) | 0 (79) |
| Yield (t/ha Fwt) from the best N treatment * | 40.4 | 11.9 |

**The lowest N application treatment above which no further significant increases in yield were obtained.*

The shoot N content for plants from the most productive N treatments have been summarised in Table C. These data are broken down into N in the organic form (i.e. integrated into the shoot tissue) and in the nitrate (or NO3-N) form (i.e. N which has been taken up but was not necessarily required for growth i.e. luxury feeding); as well as the more conventional total N form which would be available in routine analyses. As these data represent samples taken from different stages of crop development they provide a reference source against which growers can compare their own analyses to check on crop progress.

It is clear from these data that most of the total N in the coriander shoot tissue was in the organic form. Organic N declined as the crop matured whilst the accumulation of the excess NO3-N increased. Guidelines for mineral N content for coriander have not been found in the literature but data for lettuce and spinach suggest that levels should be below 3,500 to 4,000 mg/kg (EU Regulation 563/2002) which equates to 0.4% and therefore within the range measured here.

**Table C.** *Coriander shoot N content for plots producing maximum growth.*

| sample / drilling | % Organic N | % $NO_3$-N | % Total N |
|---|---|---|---|
| WHRI | | | |
| interim 1 sample (at 4-5 true leaves) | 4.0-5.1 | 0.2-0.8 | 4.3-5.7 |
| interim 2 sample (at 7-9 true leaves) | 3.3-5.0 | 0.3-0.9 | 4.2-5.4 |
| Final harvest sample | 2.7-4.5 | 0.1-1.1 | 3.2-5.3 |
| Valley Produce | | | |
| interim sample (at 7-9 true leaves) | 4.0-5.0 | 0.3-1.1 | 4.8-5.8 |
| Final harvest sample | 4.0-4.6 | 0.6-1.1 | 4.9-5.6 |

N offtake was also calculated using the yield data for each available N treatment producing maximum growth at final harvest stage and the relevant tissue analysis data which suggest that the level of organic N removed in coriander shoots at final harvest was 132 kg/ha N for the crop drilled in May, 52 kg/ha N for the crop drilled in July and 64 kg/ha for the crop drilled in August. The N offtake varied between crops due to the difference in dry matter yield and organic N content. The N offtake figures are based on the cropped area and would need to be adjusted if working on a gross field area basis (i.e. reduce to around 75% to account for unproductive space in wheelings and field headlands).

Provisional recommendations for fertiliser N for field grown coriander have been produced using the data generated in these trials. The assumptions supporting these recommendations are detailed in the main report.

**Table D.** *Preliminary N fertiliser recommendations (kg/ha) for coriander*.

| ‘SNS’ Index *<br>(Mineral N (kg/ha) to 90cm) | 0<br>(50) | 1<br>(70) | 2<br>(90) | 3<br>(110) | 4<br>(140) | 5<br>(200) | 6<br>(250) |
|---|---|---|---|---|---|---|---|
| **Proposed rate of N** | **140** | **125** | **115** | **105** | **90** | **55** | **30** |

*(*Note: SNS index should be based on a measurement of mineral N to 30cm depth. It should be multiplied by 3 (i.e. to correct to 90cm depth) to provide the relevant SNS index)*

**Coriander – quality and shelf life**

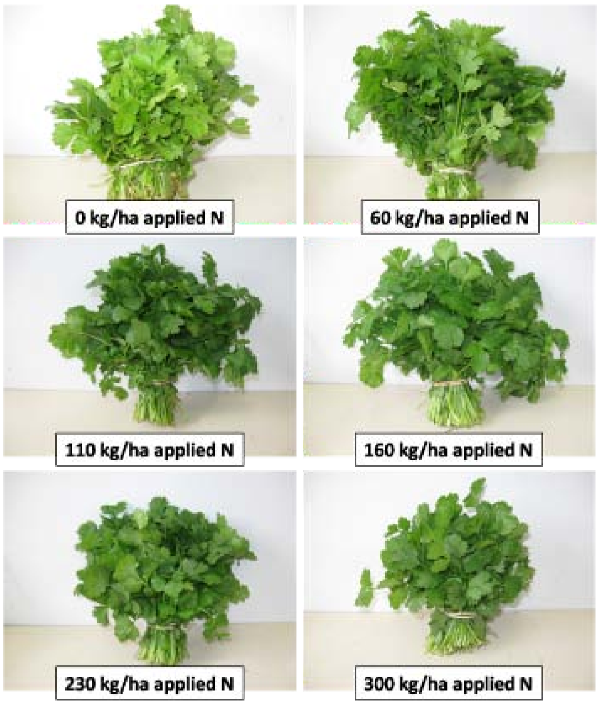


**Fig. A**. *Comparison of bunches of coriander at the start of shelf life trials from the range of applied N treatments.*

N rate also impacted on bunch quality in that foliage had a deeper green colour at higher rates of N. This can be seen in the photograph of bunches harvested from the crop drilled 23/07/09 and was also quantified through leaf greenness measurements via a hand held SPAD meter. These data suggested that bunches without N fertiliser application were less green than from the higher rates of N and the 60 kg/ha applied N rate also had lower SPAD values than higher rates from the first trial drilled. It seems likely that the 0 N treatments at least are at risk of rejection on quality grounds. However for applied N rates above 110 kg/ha (i.e. available N of 131-154 kg/ha) there were no further significant improvements in depth of leaf colour. For each of the trials drilled at Wellesbourne, product deterioration was largely as a result of wilting with bunches on average deteriorating to an unusable state by 6 to 11 days from harvest. The 0 rate of applied N (21-44kg/ha available N) overall produced the longest shelf life but also produced inferior and probably unmarketable bunch quality, as noted previously. Differences in shelf life between rates of applied N (60-300 kg/ha) were small and inconsistent. Applying extra potassium (K) as a top dressing resulted in a slight increase in shoot K content in final harvest samples but had no impact on yield or on product shelf life.

**Mint - yield**

Mint plots were planted on 05/05/09 at Wellesbourne and on 9-11/05/09 at Valley Produce (VP) from rooted transplants of Spanish mint with the aim of establishing the crop for more detailed work in the second year of the project. Rates of applied N between 0 and 300 kg/ha were tested with fertiliser applied as a base dressing prior to transplanting and then again as a top dressing each time the crop was topped. Plots were topped on two occasions in the first year (June and August) to assist establishment and then cut back at the end of the season (early October), with shoot material that was removed on each occasion quantified for ‘yield’ as well as shoot mineral content. At each harvest, the topped shoot material (tops) and remaining shoot material cut to ground level (bases) were recorded and analysed separately. At WHRI, maximum yield of mint cut at the end of the first season was associated with the highest rate of N (i.e. 200 kg/ha applied N or 229 kg/ha available N (to 30cm depth of soil) based on initial soil mineral N analysis) on each occasion.

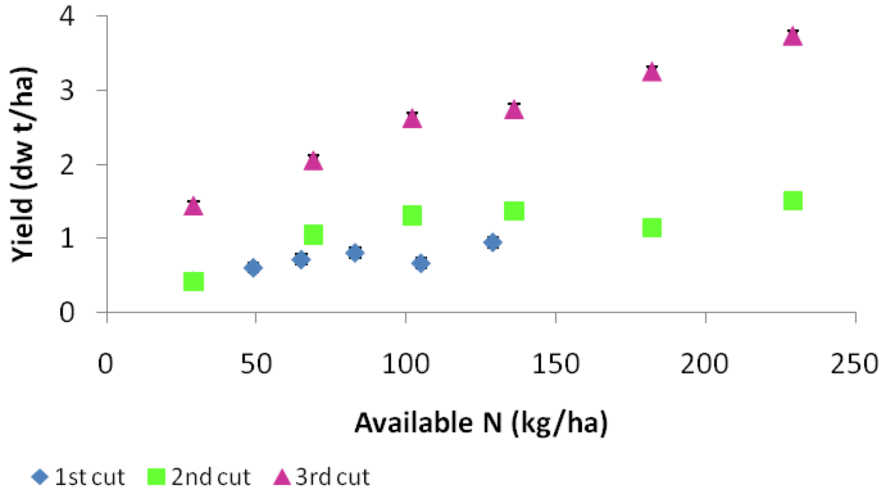


**Fig. B.** *Response of mint at Wellesbourne to available N during year 1 from two topping samples and one end of season sample.*

In year 2, the optimum available N was in the range 178-283 kg/ha for the yield of tops of all three cuts, although the difference in yield with that achieved at available N of 78-122 kg/ha was very small and only statistically significant for the second and third cuts.

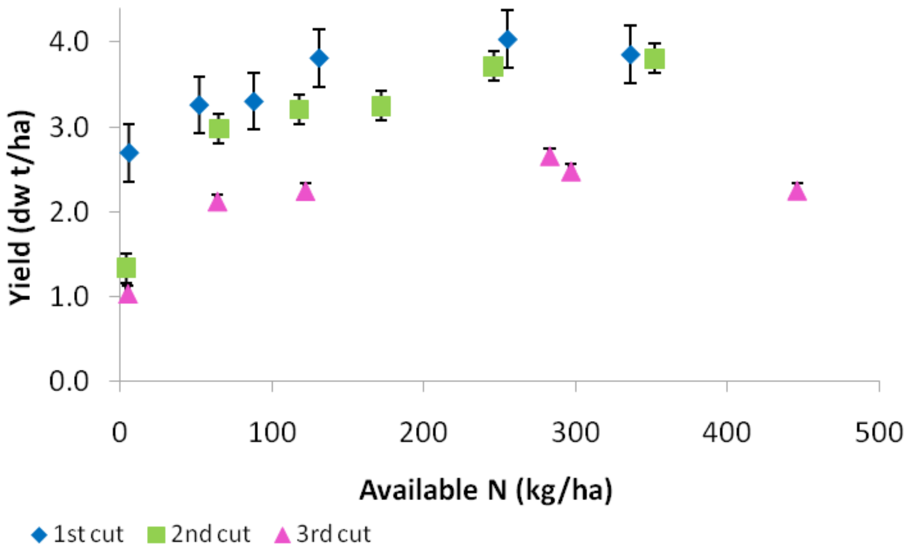


**Fig. C.** *Yield response of mint shoot tops at Wellesbourne to available N in year 2*.

Table E lists the N treatment producing maximum fresh and dry weight yield for each sample from the Wellesbourne trial together with the final fresh weight yield at harvest for the most productive N treatment for each cutting. As with coriander, since N available to the crop is a combination of that available from the fertiliser applied and that already available in the soil, the table includes a figure for available N to 30cm depth which is calculated from the mineral N analyses carried out on soil samples prior to drilling each trial plus the amount of N applied as the treatment.

**Table E.** Rate of applied (and available) N to each mint cut in Years 1 and 2 producing maximum yield, and the yields from the best treatments (Wellesbourne)

| Cutting date | 07/07/09<br>10/05/10 | 06/08/09<br>05/07/10 | 05/10/09<br>06/09/10 |
|---|---|---|---|
| Year 1 | - | - | 200 (229) |
| Year 2 | 154 (178) | 230 (246) | 160 (283) |
| Yield (t/ha Fwt) from the best N treatment * | 32.4 | 23.3 | Year 1 11.3<br>Year 2 28.4 |

**The lowest N application treatment above which no further significant increases in yield were obtained.*

In the first season, mint yield in Valley Produce trials was not responsive to available N. However, due to the lack of true replication and randomisation of N treatments in the Valley Produce trials, this result should be treated with caution. In the first cut, yield of bases was slightly higher from the 48-179 kg/ha available N rates than from higher available N rates. There were no other significant differences in yield of tops or bases from the first three cuts of the first season at Valley Produce. Due to problems of scheduling N applications and harvesting, no reliable data on response of mint yield to available N was obtained from the second season mint trial at Valley Produce, although yields and mineral analyses of plant tissue provided useful comparisons with data collected from Wellesbourne. Most of the nitrogen in mint shoots was in the organic form. Nitrogen levels were highest in the second cut of the first year.

**Table F.** *Mint shoot N content for plots producing maximum growth.*

| | % Organic N | % $NO_3$-N | % Total N |
|---|---|---|---|
| **Year 1** | | | |
| 1st Cut | 2.41 | 0.01 | 2.42 |
| 2nd Cut | 4.03 | 0.26 | 4.29 |
| 3rd Cut | 2.31 | 0.03 | 2.35 |
| **Year 2** | | | |
| 1st Cut | 3.48 | 0.08 | 3.56 |
| 2nd Cut | 2.88 | 0.02 | 2.90 |
| 3rd Cut | 2.82 | 0.07 | 2.89 |

N offtake was also calculated using the yield data for each available N treatment producing maximum crop growth at harvest and the relevant tissue analysis data which suggest that the level of organic N removed in mint shoots at harvest ranged from 15 kg N/ha in the first cut of Year 1 to 179 kg N/ha in the first cut of the second year (equivalent to 11.3 and 134.3 kg N /ha allowing for 25% unproductive area).

Provisional recommendations for fertiliser N for field grown mint have been produced using the data generated in these trials. The assumptions supporting these recommendations are detailed in the main report. These recommendations are for each cutting in an established crop in the second year of production.

The figures in Table G assume that the base material from the shoots (and the associated nitrogen content) is removed from the field after cutting. If the bases remain in the field after cutting, the figures should be reduced by 30 kg/ha N to allow for the nitrogen content of the shoot bases which becomes available to the next cutting.

**Table G.** *Preliminary N fertiliser recommendations for each cutting of established mint crops.*

| **'SNS' Index *** | **0** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| ***(Mineral N (kg/ha) to 90cm)*** | ***(50)*** | ***(70)*** | ***(90)*** | ***(110)*** | ***(140)*** | ***(200)*** | ***(250)*** |
| **Proposed rate of N (base mowing removed)** | **180** | **170** | **160** | **150** | **130** | **100** | **70** |

*(*Note: SNS index should be based on a measurement of mineral N to 30cm depth. It should be multiplied by 3 (i.e. to correct to 90cm depth) to provide the relevant SNS index)*

### Mint – quality and shelf life

In year 1, leaf greenness (as measured by a SPAD meter) at the start of shelf life was not influenced by level of available N. However, in Year 2 of the crop, leaf greenness of mint was improved by N applications, but there were no further increases in greenness at levels of available N above 122-172 kg/ha. The samples from the second cutting were greener than those from the first and third cuttings.

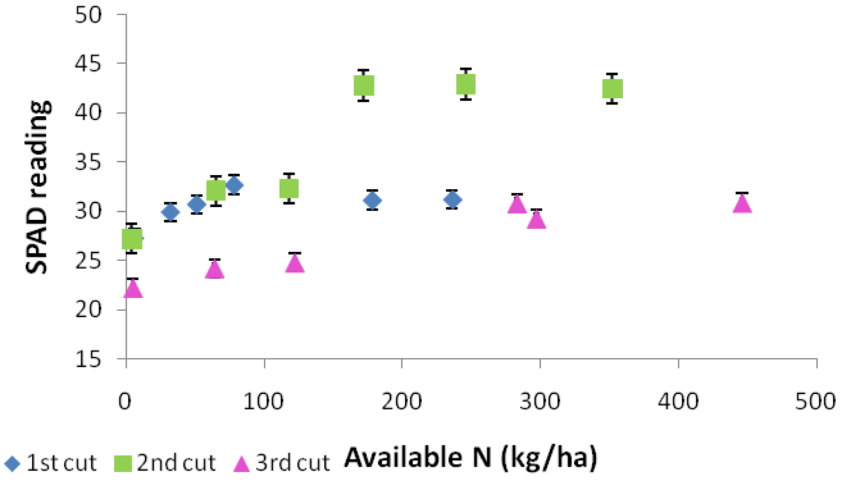


**Fig. D**. *Effect of available N on leaf greenness of bunches of mint at the start of shelf life.*

Bunches of mint harvested at the end of the first season when the crop was cut back were assessed for shelf life but leaf disease rendered them unfit for use two weeks after harvest. Within this period, the rate of N applied during production did not influence shelf life in storage. The main cause of shelf life failure in Year 2 was also browning/necrosis. Samples from the first cut had a longer shelf life than those from the second and third cuts. The effect of available N on shelf life also differed between the first cut and the second and third cuts. In the first cut, samples from plots with available N of 51-78 kg/ha had a significantly longer shelf life than samples from plots with lower or higher levels of available N. However, in the two later cuts in Year 2, increasing levels of available N reduced shelf life, with a difference of five days between the lowest and highest available N levels.

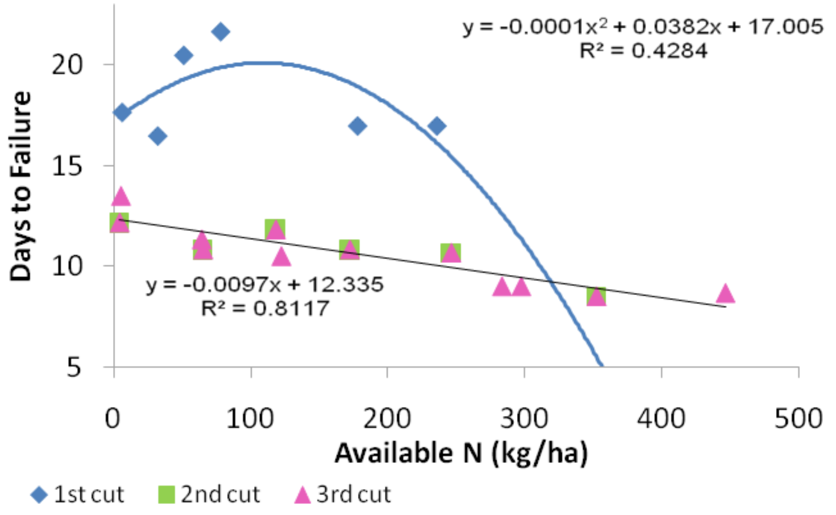


**Fig. E.** *Effect of available nitrogen on days to failure in shelf life (mainly due to leaf necrosis and some yellowing).*

## Financial benefits

By identifying optimum rates of available N for crop yield, there is an immediate cost saving in avoiding the use of excess N fertiliser. As a case study, the coriander crops at Valley Produce are likely to have been treated with N at the 160 kg/ha rate. At an SNS index of 5 (using the value of SMN to 90 cm of 203 kg/ha from the values in Table 5, VP drilling 17/06/09 and Table B of the current version of RB209 for a medium soil in rotation) the recommended application rate would be reduced to 55 kg/ha. This would equate to a saving of 105 kg/ha N, and at an estimated fertiliser N cost of £175 per tonne for a 34% N product, would be worth £54 per ha per crop which with the potential for three crops per year would be £163 per ha per annum.

The results for mint have shown that increases in available N above 78-122 kg/ha resulted in only very small increases in yield (if any), were unnecessary in terms of product greenness, and can have a detrimental effect on shelf life in terms of leaf browning/necrosis.

The benefits of being able to justify fertiliser inputs for produce assurance schemes are essential for some businesses in order comply with customer demands as well as meeting obligations to minimise impact on the environment.

## Action points for growers

- Growers should review their current fertiliser programmes in line with the data generated for coriander in the first year and for mint in the first and second years of this project. Typical shoot N concentrations and N offtake for well grown crops are included in this grower summary as well as an RB209 format recommendation table. Guidance for establishing SNS levels is given in HDC News No. 162 (April 2010, p14).

- Applying the correct rate of N will ensure optimum yield, quality (in terms of greenness) and shelf life (delayed browning/necrosis of mint) as well as efficient returns on fertiliser inputs and minimised leaching of N.

- Growers requiring information about the wider range of mineral elements required to produce a healthy crop should refer to tables in the main report where concentrations of a wider range of nutrients are summarised from the analytical data compiled from these trials. Whilst the trials here did not attempt to optimise this wider range of nutrients, the data should provide at least an indication of nutrient status for well grown crops.

# SCIENCE SECTION

## Introduction

The principles of crop nutrition are well established. Plants respond to increasing levels of nutrients by increasing vegetative growth, providing available nutrients are in a suitable balance and up to a critical level. Beyond this point, increased availability results in waste in terms of receiving no further benefit from the fertiliser applied. Excess nutrient will also increase the risk of diffuse pollution.

Historically growers have been supported by guidelines for fertiliser use through the MAFF / DEFRA publication RB209 which contains tables that link current nutrient status of the soil with recommended levels of fertilisers according to the demands of specific crops. However there are no guidelines for herbs within the current or revised version of the RB209 fertiliser manual. The assured produce scheme protocol for herbs provides guidance for fertiliser applications for field production based on international work but states that with no input specific to UK soils and climate they cannot be considered to be precise.

There is therefore a clear gap in knowledge with regard to nutrient requirements of UK grown herb crops despite the considerable value and expansion of the UK herb industry seen in recent years. Market data for the multiples sector suggest a current total market value of around £77 Million which reflects an 11 to 14% year on year increase from 2006.

Whilst it is possible to design experiments evaluating response to a range of macro and micronutrients, such work would be expensive to carry out. Furthermore, UK herb production includes a range of species encompassing short term herbaceous types that are cut back and re-drilled through to perennial types giving multiple harvests during the course of a season. In order to develop work that both improves the current knowledge base of herb growers and delivers information promptly, studies undertaken required some focus. This project therefore examines response to nitrogen. Correct N availability would be expected to best optimise production of leaves, the top priority for UK production. In addition, given its mobility within the soil solution, it is especially important to match N application as closely as possible to demand in order to minimise pollution. Rates of other nutrient elements would then be applied according to current practice with the aim of ensuring no limitation to growth by elements other than nitrogen as the main focus of the work. Data collected from experiments will then be used to determine critical N (i.e. estimated N concentration of an optimally fertilised whole plant) which along with expected yield, will be used to calculate N requirement as described by Rahn (2008).

Discussion with the British Herbs Trade Association Technical Committee identified coriander and mint as appropriate species for investigation, being both in the top five in terms of commercial importance within UK production and providing contrasting production systems to study being annual and perennial respectively.

Examples of previous work published for the species to be studied within this project include reports of responses of coriander for seed production to N applied either as mineral or organic fertilisers, e.g. Tripathi (2006), Garg (2004), Kumar et al (2002) in India. Typical rates of N used in these studies were 0 to 90 kg/ha. Trials carried out in Australia have examined response to micronutrients of coriander for seed production (Hooper and Dennis, 2002). Work on mint (*Mentha arvensis*) in India suggests rates of N between 150 and 250 kg/ha are required to optimise yield (Ram *et al*., 2006) and in the northern US, N rates of 224 to 280 kg/ha are recommended for spearmint (*M. spicata*) and peppermint (*M. piperta*) (Brown *et al*., 2003). Studies in Bulgaria examining N fertiliser applications within the range 0 to 534 kg/ha indicate that higher rates of N increased biomass of different cultivars of mint (Zheljazkov and Margina, 1996) and also increased yield of essential oils (i.e. with % essential oil recovery either increased or at least constant in response to increasing N). In contrast to the work in Bulgaria, research in the midwestern US found that more than 179 kg/ha N promoted overgrowth and lodging with a consequent reduction in dry matter yield and therefore also essential oil yield (Alkire and Simon, 1996). Yield responses of crops from different parts of the world may relate to totally different management practices, for example the mint production would probably have been aimed at oil production from dried herb, where there are less frequent cuts from a taller crop. Similarly with coriander crops aimed at seed production rather than leaves. Clearly the definition as to what is a ‘high’ level of N to apply varies, which will be in part due to differences in N available within the soil via mineralization, as well as expected herb yields and general climatic conditions. This highlights the difficulty of transferring results between different environmental conditions as well as the importance of maintaining crop quality when increasing crop biomass. Whilst not directly transferrable to the UK production system, data available from these publications such as leaf mineral analysis, may be useful for comparative purposes against data collected in the work detailed in this report.

As well as aiming to maximise productivity, herb growers strive to produce good final quality which includes postharvest longevity. Hence bunched product from all treatments will be evaluated for postharvest life. In addition, specific treatments will be applied to coriander crops which are designed to follow up on interesting results from hydroponic production of coriander from the project PC 259 (Flowers and Bashtanova, 2008); where the addition of NaCl improved product shelf life. Since NaCl may be expected to impair soil quality through raising conductivity in these field based experiments, exposure to increased osmotic stress will be evaluated by increasing concentration of available K.

## Materials and methods

*Preparation and treatments - Coriander:*

Coriander variety Filtro was drilled on three occasions (21/05/09, 23/07/09 and 11/08/09) in plots at Warwick University, Wellesbourne (WHRI) (following a winter barley crop) and on two occasions (17/06/09 and 11/08/09) in plots (following a spinach crop) at the commercial site (Valley Produce's Alton site, VP). Seed were drilled as 10 rows across the bed (1.8m wide) and at a density of 22 mm between seed along the row (i.e. 250 seed per $m^2$ planted bed area).

All batches of coriander were tested for response to nitrogen by applying a calcium ammonium nitrate (WHRI plots) or ammonium nitrate (Valley Produce plots) fertiliser at a range of levels as detailed in Table 1. Application was split as one third as a base dressing and two thirds as a top dressing at WHRI and applied by hand with base dressings worked in with a Dutch Harrow. All the N applied at Valley Produce was as a top dressing applied via a tractor mounted spreader. The top dressing at WHRI was applied at the 3-5 true leaf stage and irrigated in.

Additional treatments at WHRI were designed to examine how increasing osmotic stress might impact coriander shelf life. These treatments consisted of a top dressing of potassium sulphate at 166 kg/ha K (i.e. 200 kg/ha $K_2O$). High K treatments were combined with N applied at either low (60 kg/ha), standard (160 kg/ha) or high (230 kg/ha) rates.

The randomised plot design used at WHRI consisted of plots 1.83m by 3m to allow for adequate interim and final samples to be accommodated and properly guarded. There were four replicate plots of each main treatment which were divided across the three beds as illustrated in Figure 1.

Since N was applied over a larger trial area using a tractor mounted spreader, plots at VP were arranged sequentially along the length of the trial beds. Replicate plots therefore were taken as individual beds but this design was not able to provide a measure of variability along the length of the beds. Plot layout for VP is given in Figure 2.

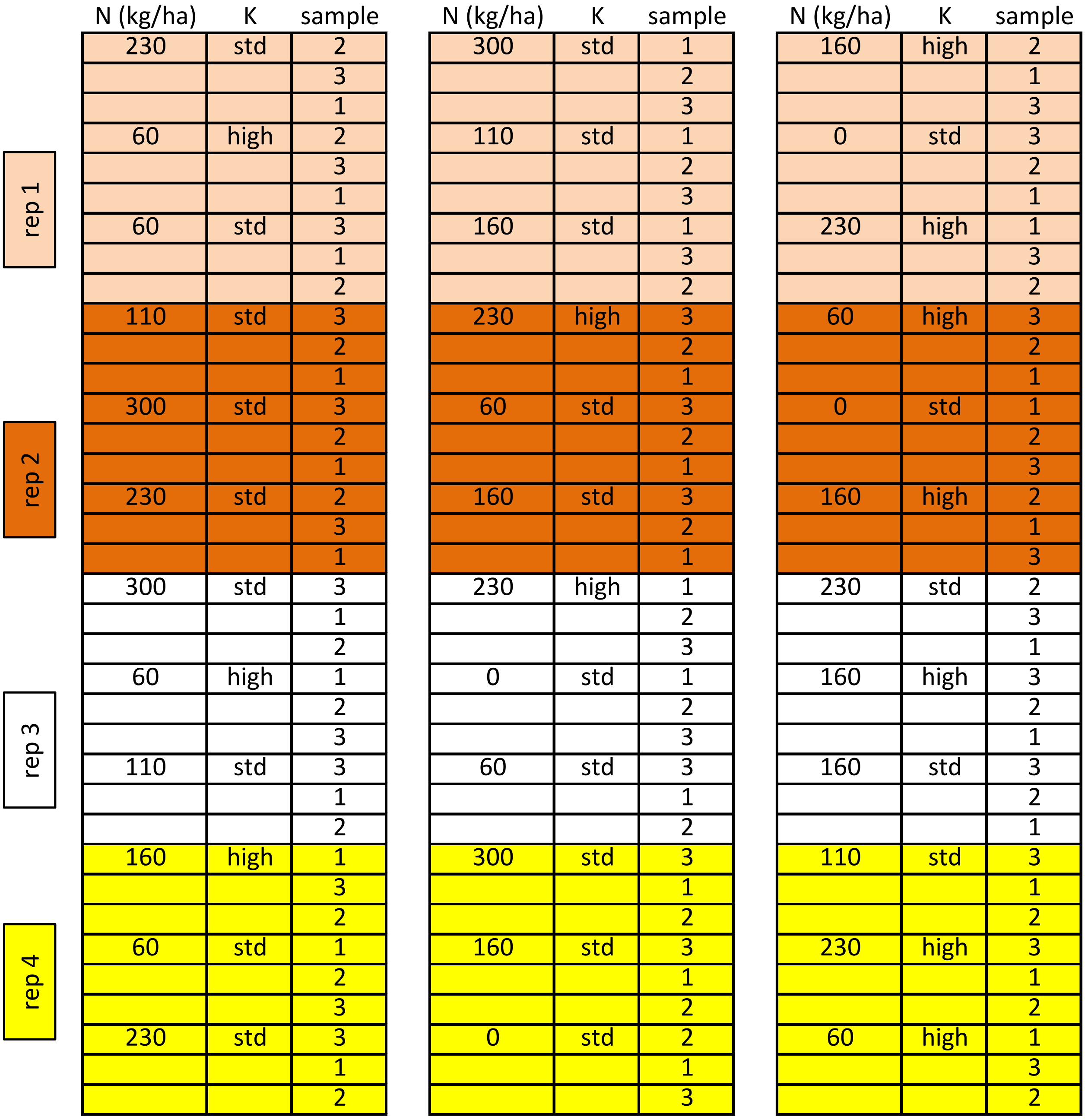
Coriander plots were assessed via interim and final samples as detailed in Table 2. WHRI plots were sampled more frequently as treatments started at the base dressing stage and hence effects could be expected from crop emergence onwards. VP plots were sampled from one week after top dressing onwards since there would be no treatment response prior to top dressing in this case, and also at final harvest stage.

On each occasion, a sample of coriander shoot tissue was removed from the plot by cutting stems at the surface of the soil. At WHRI, the sample comprised of the centre 8 rows of plants along a 0.5 m length of bed; plants were sampled wherever their roots fell within this designated area. The position the sampling point was determined by producing a randomised sampling plan which is illustrated in Figure 1. At VP a quadrat designed to cover an 0.5 m$^2$ area was used to define sample area, all plants with roots within this area were removed on each occasion.

**Table 1.** Summary of treatments applied to WHRI and VP coriander plots

| **Dates of fertiliser applications to the trials at WHRI and VP:** | |
|---|---|
| **WHRI drillings (AN at 27% N applied at 0, 60, 110, 160, 230 or 300 kg/ha)** | |
| Drilled 21/05/09 | |
| Base (at 1/3 total rate) applied:-<br>Top dressing (at 2/3 total rate) applied :- | 20/05/09<br>23/06/09 |
| Drilled 21/05/09 | |
| Base (at 1/3 total rate) applied:-<br>Top dressing (at 2/3 total rate) applied :- | 20/07/09<br>14/08/09 |
| Drilled 21/05/09 | |
| Base (at 1/3 total rate) applied:-<br>Top dressing (at 2/3 total rate) applied :- | 10/08/09<br>07/09/09 |
| **VP drillings (AN at 34.5% N applied at 0, 52, 131, 204 or 276 kg/ha N)** | |
| Drilled 17/06/09 - full rate application | 14/07/09 |
| Drilled 11/08/09 – full rate application | 09/09/09 |

WHRI Coriander:



| | N (kg/ha) | K | sample | N (kg/ha) | K | sample | N (kg/ha) | K | sample |
|---|---|---|---|---|---|---|---|---|---|
| rep 1 | 230 | std | 2 | 300 | std | 1 | 160 | high | 2 |
| | | | 3 | | | 2 | | | 1 |
| | | | 1 | | | 3 | | | 3 |
| | 60 | high | 2 | 110 | std | 1 | 0 | std | 3 |
| | | | 3 | | | 2 | | | 2 |
| | | | 1 | | | 3 | | | 1 |
| | 60 | std | 3 | 160 | std | 1 | 230 | high | 1 |
| | | | 1 | | | 3 | | | 3 |
| | | | 2 | | | 2 | | | 2 |
| rep 2 | 110 | std | 3 | 230 | high | 3 | 60 | high | 3 |
| | | | 2 | | | 2 | | | 2 |
| | | | 1 | | | 1 | | | 1 |
| | 300 | std | 3 | 60 | std | 3 | 0 | std | 1 |
| | | | 2 | | | 2 | | | 2 |
| | | | 1 | | | 1 | | | 3 |
| | 230 | std | 2 | 160 | std | 3 | 160 | high | 2 |
| | | | 3 | | | 2 | | | 1 |
| | | | 1 | | | 1 | | | 3 |
| rep 3 | 300 | std | 3 | 230 | high | 1 | 230 | std | 2 |
| | | | 1 | | | 2 | | | 3 |
| | | | 2 | | | 3 | | | 1 |
| | 60 | high | 1 | 0 | std | 1 | 160 | high | 3 |
| | | | 2 | | | 2 | | | 2 |
| | | | 3 | | | 3 | | | 1 |
| | 110 | std | 3 | 60 | std | 3 | 160 | std | 3 |
| | | | 1 | | | 1 | | | 2 |
| | | | 2 | | | 2 | | | 1 |
| rep 4 | 160 | high | 1 | 300 | std | 3 | 110 | std | 3 |
| | | | 3 | | | 1 | | | 1 |
| | | | 2 | | | 2 | | | 2 |
| | 60 | std | 1 | 160 | std | 3 | 230 | high | 3 |
| | | | 2 | | | 1 | | | 1 |
| | | | 3 | | | 2 | | | 2 |
| | 230 | std | 3 | 0 | std | 2 | 60 | high | 1 |
| | | | 1 | | | 1 | | | 3 |
| | | | 2 | | | 3 | | | 2 |

**Figure 1.** Plot layout for coriander trials at Wellesbourne (WHRI)

VP Coriander:

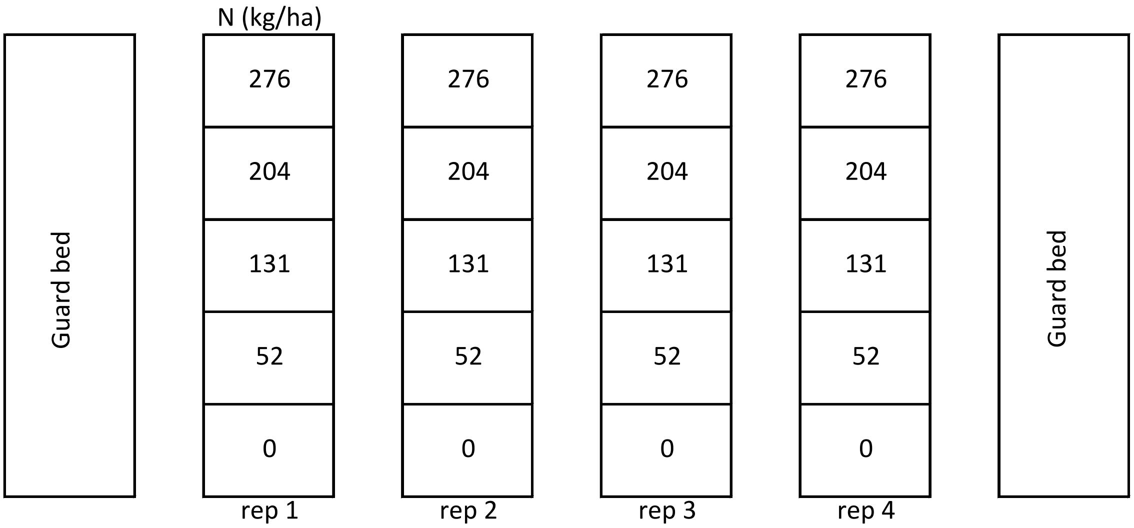


**Figure 2.** Plot layout for coriander trials at Valley Produce (VP)

**Table 2.** Sampling schedule for coriander plots

| Date drilled | Date of 1st sample | Date of 2nd sample | Date of 3rd sample |
|---|---|---|---|
| **WHRI:** | | | |
| 21/05/09 | 19/06/09 | 01/07/09 | 09/07/09 |
| 23/07/09 | 13/08/09 | 24/08/09 | 01/09/09 |
| 11/08/09 | 04/09/09 | 14/09/09 | 29/09/09 |
| **VP:** | | | |
| 17/06/09 | | 23/07/09 | 30/07/09 |
| 11/08/09 | | 22/09/09 | 08/10/09 |

*Preparation and treatments - Mint:*

Spanish mint (*Mentha spicata)* from cuttings taken at Valley Produce were rooted in modules and then planted into prepared beds on 05/05/09 at WHRI (following a winter barley crop) and on 10/05/09 (following a chard crop) at VP. These mint crops were tested for response to nitrogen by applying calcium ammonium nitrate (WHRI plots) or ammonium nitrate (Valley Produce plots) fertiliser at a range of levels as detailed in Table 3. The base dressing of N at WHRI was applied by hand and worked in with a Dutch harrow; subsequent top dressings were applied by hand and irrigated in. At VP N was applied using a tractor mounted spreader. Top dressings were applied at the same rates as detailed in Table 2 after each topping except for the end of Year 1 season topping where application was delayed until the start of the next (2010) season.

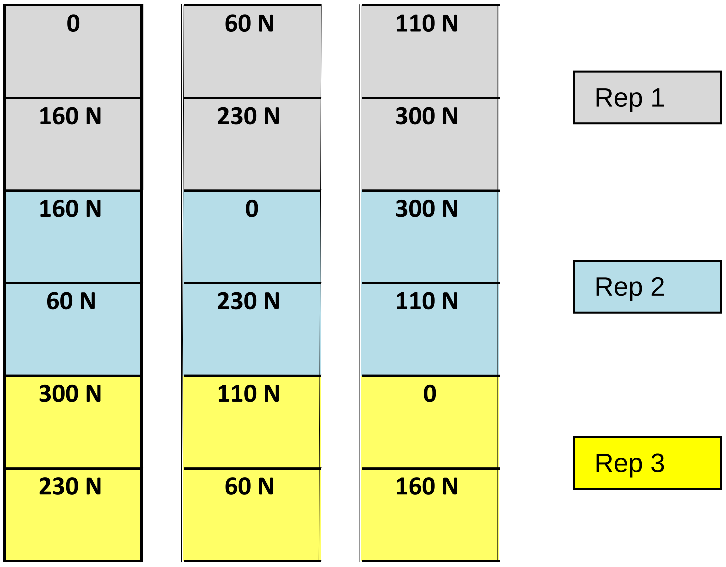
Due to problems with scheduling of N applications and harvesting, no reliable N response data was obtained from the second season of the mint trial at VP. However, maximum mint yields from the WHRI and VP sites were compared for each cut.

**Table 3.** Summary of treatments applied to WHRI and VP mint plots

| **Dates of fertiliser applications to the trials at WHRI and VP:** | |
|---|---|
| **WHRI trials (CAN at 27% N applied at 0, 60, 110, 160, 230 or 300 kg/ha)** | |
| Base (at 1/3 total rate) applied:- | 01/05/09 |
| Top dressing (at 2/3 total rate) applied :- | 14/07/09 |
| | 12/03/10 |
| Full rate applied:- | 27/05/10 |
| Full rate applied: | 19/07/10 |
| **VP drillings (AN at 34.5% N applied at 0, 52, 131, 204 or 276 kg/ha N)** | |
| Full rate applied:- | 18/05/09 |
| | 14/07/09 |
| | 07/03/10 |

The randomised plot design used at WHRI consisted of plots 1.83 m by 3 m to allow for sample areas and guards. There were three replicate plots of each main treatment which were divided across the three beds as illustrated in Figure 3. Plants were spaced at 30 cm apart both across the bed and within the row. One plot at WHRI comprised of 44 plants with the outer row of each bed nominally assigned to guards along with the 2 rows across each end of the plot. A gap of 0.5 m was left between adjacent plots and trials beds were alternated with empty beds to minimise the potential for runners producing shoots in one plot benefitting from the N available in another plot. Samples were taken from a set 1 $m^2$ area.
Since N was applied over a larger trial area using a tractor mounted spreader, plots at VP were arranged sequentially along the length of the trial beds. Replicate plots therefore were taken as individual beds but this design was not able to provide a measure of variability along the length of the beds. Plot layout for VP is given in Figure 4.

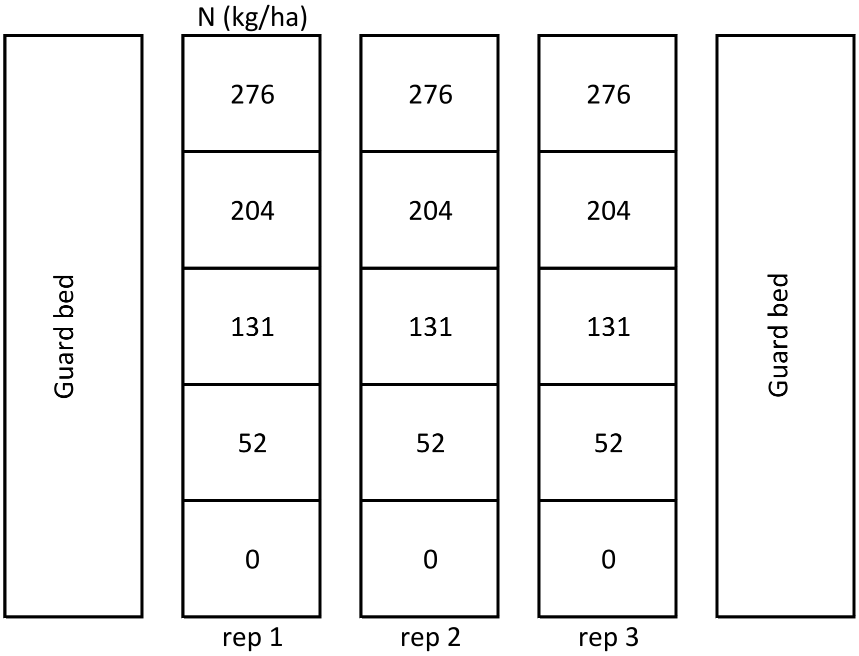
Mint plots were not in standard production in year 1 as they were becoming established, however plots had to be topped in order to encourage branching, at which point shoot material removed as part of the topping process was assessed (Table 4). A final sample was also removed at the end of the first season when plants would normally be cut back. The portion of stem removed for topping was assessed for yield on each occasion. The base of these plants was left in place in the WHRI plots to represent normal practice (i.e. topping being designed to remove top growth and promote branching of the lower stem). At VP, however, where plots were bigger, it was possible to also remove the base material without impacting future samples by sampling a different area of the plot on each occasion. This was therefore used to provide an estimate of a typical proportion of crop removed by topping. At the end of the season all plots were cut back to ground level with ‘tops’ and ‘bases’ separated since the tops would provide some marketable yield but the bases of stems would also be cut back in commercial systems.



| | | | |
|---|---|---|---|
| 0 | 60 N | 110 N | Rep 1 |
| 160 N | 230 N | 300 N | Rep 1 |
| 160 N | 0 | 300 N | Rep 2 |
| 60 N | 230 N | 110 N | Rep 2 |
| 300 N | 110 N | 0 | Rep 3 |
| 230 N | 60 N | 160 N | Rep 3 |

**Figure 3.** Plot layout for mint trials at WHRI

VP Mint:



| Guard bed | N (kg/ha) | | | Guard bed |
|---|---|---|---|---|
| | 276 | 276 | 276 | |
| | 204 | 204 | 204 | |
| | 131 | 131 | 131 | |
| | 52 | 52 | 52 | |
| | 0 | 0 | 0 | |
| | rep 1 | rep 2 | rep 3 | |

**Figure 4.** Plot layout for mint trials at VP

*Soil nutrient status – coriander and mint*

Mineral N status was assessed on soil cores of 0-30 cm, 30-60 cm and 60-90 cm depths sampled immediately prior to drilling/planting and also after final harvest. Multiple samples were taken and pooled for analysis to ensure representative sampling. Mineral N was assessed on fresh soil samples.

**Table 4.** Topping / sampling schedule for mint trials in years 1 (2009) and 2 (2010)

| | WHRI | VP |
|---|---|---|
| **Year 1** | | |
| Topping sample 1 | 7 July | 30 June |
| Topping sample 2 | 6 August | 23 July |
| Topping sample 3 | 5-7 Oct | 22 Sep |
| **Year 2** | | |
| Topping sample 1 | 10 May | 11 May |
| Topping sample 2 | 5 July | 7 July |
| Topping sample 3 | 6 Sept | 7 Sept |

*Assessments – coriander and mint*

Samples removed from coriander and mint trials were assessed for:

Total fresh weight

Total dry weight (oven dried for at least 48 hours at 80°C)

Leaf mineral analysis on dried whole shoot material

Average rooting depth was also assessed at final harvest stage of coriander and at the end of the first season and during July of the second season for mint by digging a trench adjacent to plots fertilised at the ‘standard’ level (160 kg N /ha) and measuring maximum rooting depth.

In addition, at final harvest stage, a sub sample of both mint and coriander shoots from each plot at WHRI was bunched (at approximately 100g/bunch for mint and 120g/bunch for coriander) for shelf life assessment. Bunched product was kept in a shaded area and moved to a forced air system (Figure 5) for pre-cooling promptly after cutting with each bunch in a separate polythene bag wrapped around the bunch but left open for air exchange. Bunches were cooled in the forced air system for 24 hours before being stored in crates in the 4°C cold store for regular assessments of the following parameters:

Bunch weight

Leaf greenness *(measured with a SPAD meter using the average value for five leaves taken from around the upper leaves in the bunch)*

Bunch wilting (qualitative score):

0 – no wilting
1- slight wilting
2- severe wilting

Incidence of yellowing (qualitative score)

0 – no yellowing
1- slight yellowing
2- severe yellowing

*This score supplements the SPAD results since yellowing tended to occur as a few leaves lower down in the bunch rather than a general yellowing of overall bunch colour.*

Incidence of necrosis (qualitative score)

0 – no necrosis
1- slight necrosis
2- severe necrosis

Store life (days); assessed as the time to product reaching a score of 2 on one of the qualitative scores.

Appendix 1 provides photographs which illustrate the qualitative scoring system.

**Figure 5.** Pre-cooling system being loaded with bagged coriander bunches

## Results

### *Coriander response to N*

*Initial soil mineral status*

The initial N status of trial plots varied with both location and timing (Table 5) with higher initial N levels in the plots at VP compared with WHRI.

**Table 5.** Mineral N levels in soil cores taken immediately prior to drilling trials

| Sample depth | $NO_3$-N (µg/g) | $NH_4$-N (µg/g) | $NO_3$-N (µg/g) | $NH_4$-N (µg/g) |
|---|---|---|---|---|
| | WHRI drilled 21/05/09 | | VP drilled 17/06/09 | |
| 0-30 cm | 5.21 | 1.15 | 56.97 | 3.47 |
| 30-60 cm | 3.43 | 1.42 | 11.42 | 3.17 |
| 60-90 cm | 2.12 | 1.75 | 23.51 | 3.21 |
| | WHRI drilled 23/07/09 | | | |
| 0-30 cm | 9.50 | 1.59 | | |
| 30-60 cm | 4.89 | 1.43 | | |
| 60-90 cm | 3.43 | 1.55 | | |
| | WHRI drilled 11/08/09 | | VP drilled 11/08/09 | |
| 0-30 cm | 4.72 | 0.46 | 18.22 | 1.48 |
| 30-60 cm | 8.29 | 0.64 | 9.94 | 1.27 |
| 60-90 cm | 5.23 | 0.47 | 5.51 | 0.85 |

Available N was calculated by adding N applied as fertiliser to the N assumed to be available from residual levels within the soil to the estimated rooting depth for the crop. To convert the mineral analysis data (expressed as µg/g) for each initial sample into kg/ha of soil the following calculation was used:

$$\text{kg/ha N from soil} = \frac{\text{(soil bulk density x depth of sample)}}{10} \times \text{total N in sample (µg/g)}$$

where bulk density was assumed to be 1.33 and rooting depth was within the first 30 cm of the soil, based on measurements made on mature crops in plots at WHRI.

Hence:

Available N = soil mineral N to 30cm (pre-planting) + Fertiliser applied to plots

The calculated levels of available N for each trial are summarized in Table 6.

**Table 6.** Available N calculated from mineral analysis of the 0-30cm soil sample and applied fertilizer, in coriander N treatment plots

| **WHRI:** | **Rate of N applied (kg/ha)** | | | | | |
|---|---|---|---|---|---|---|
| Drilling date | 0 | 60 | 110 | 160 | 230 | 300 |
| 21/05/09 | 25 | 85 | 135 | 185 | 255 | 325 |
| 23/07/09 | 44 | 104 | 154 | 204 | 274 | 344 |
| 11/08/09 | 21 | 81 | 131 | 181 | 251 | 321 |

| **VP:** | **Rate of N applied (kg/ha)** | | | | |
|---|---|---|---|---|---|
| Drilling date | 0 | 52 | 131 | 204 | 276 |
| 17/07/09 | 241 | 293 | 372 | 445 | 517 |
| 12/08/09 | 79 | 131 | 210 | 283 | 355 |

*Growth analysis:*

The influence of available N on yield varied with time of drilling, time of sampling and trial site (Figures 6 and 7).In WHRI trials, N was found to have a significant influence over dry weight yield of all samples except the interim 2 sample of the second crop (drilled 23/07/09) and the interim 1, interim 2 and final samples of the third crop (drilled 11/08/09). The rate of N producing the highest yield for each WHRI trial are summarised below:

WHRI drilled 21/05/09: Yield measured from the first two interim samples increased with increasing level of available N and the highest rate of available N (325 kg/ha available N equivalent to 300 kg/ha N applied) produced the highest yield. For the final harvest sample, the 255 kg/ha level of available N (i.e. 230 kg/ha N applied) produced the highest yield (with no significant improvement at the next rate of N of 325 kg/ha applied N).

WHRI drilled 23/07/09: Yield was highest for the 204 kg/ha rate of available N (160 kg/ha N applied) for the first interim sample and for the 154 kg/ha rate of available N (110 kg/ha applied N) for the second interim and final samples.

WHRI drilled 11/08/09: Yield was highest for the 81 kg/ha rate of available N (60 kg/ha applied N) for all samples. Response was less pronounced for this final crop however than for the first two crops at WHRI, and as summarized previously not found to be statistically significant.

For experiments at VP, N rate had a significant influence over yield for all samples except the final sample taken from the crop drilled on 17/06/09. The rate of N producing the highest yield for each VP trial are summarised below:

VP drilled 17/06/09: Yield was highest at the 293 kg/ha rate of available N (60 kg/ha applied N) for both samples taken (although response was minimal for the final sample).

VP drilled 11/08/09: Yield was highest at the 131 kg/ha level of available N (60 kg/ha applied N) for the interim 1 sample, with the increase at the 355 kg/ha rate of available N (276 kg/ha applied N) assumed to be anomalous. The 79 kg/ha level of available N (i.e. 0 applied N) produced equivalent or higher yield to the 131 to 210 kg/ha levels of available N plots for the final sample which again suggests the increase in yield associated with the 276 kg/ha available N plot is anomalous.

As noted in the methods, treatments at VP were applied sequentially along the field and there is no measure of how position in the field may have influenced yield or interacted with N rate applied.

Response of fresh weight yield followed that described above for dry weight yield. In order to put this data in perspective the maximum fresh weight yields at final harvest are detailed in Table 7. Yield from the earliest drilling was greatest at both sites and was also comparable between the two sites. There was greater variation between the two sites for the latest crop drilled with higher yield produced by the WHRI plots than the VP plots, despite the longer production period at VP. Since this data represents yield per unit cropped area, and assuming around 20% of the cropped area would be unproductive (wheelings) with a further 5% as headland space, yield per unit total field area would be approximately 75% of this total figure i.e. 36.7 t/ha as the highest total fresh weight yield produced and 11.7 t/ha as the lowest total fresh weight yield.

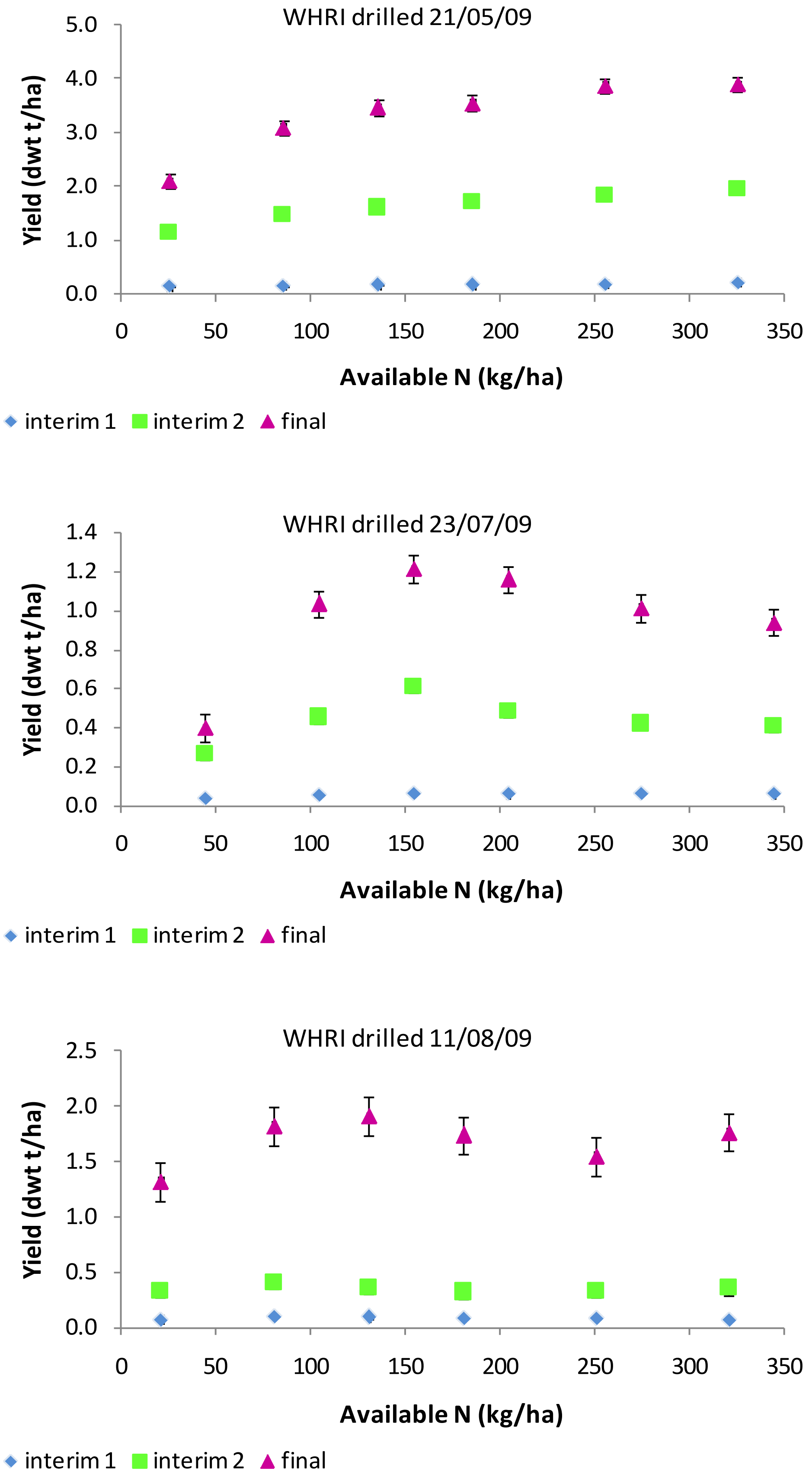
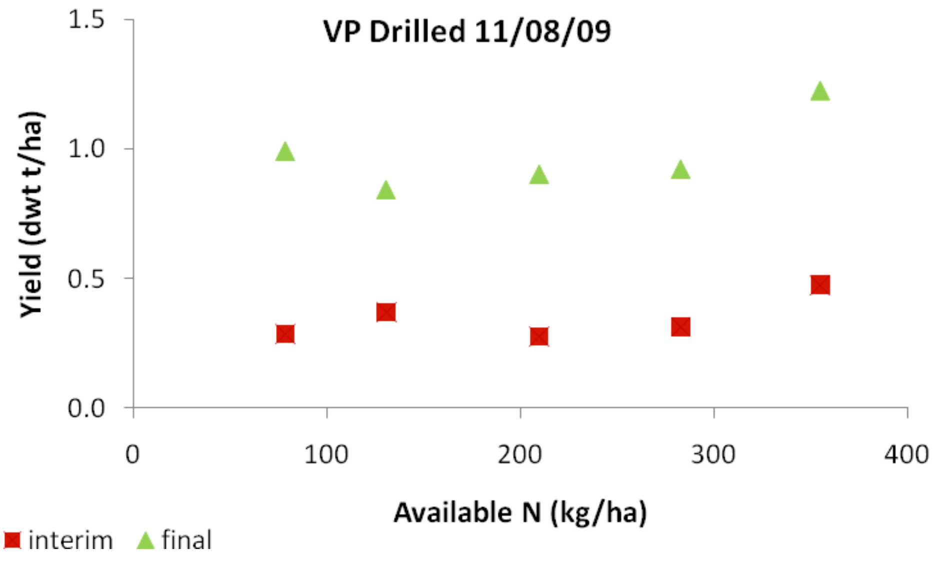


**Figure 6.** *Shoot dry weight yield from interim and final coriander harvests of WHRI plots in response to N available to 30cm depth of soil (error bars indicate standard error which, in some cases, are obscured by the size of the data point).*



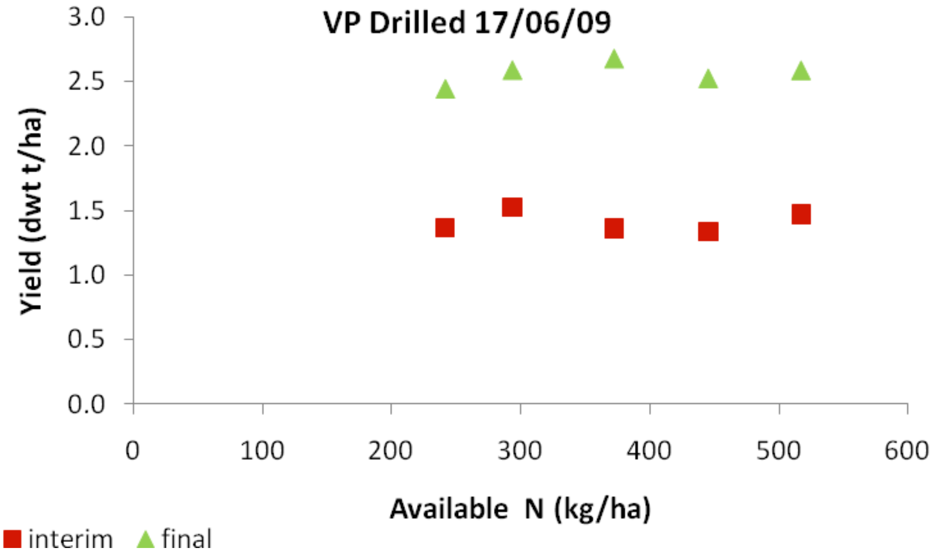


**Figure 7.** *Shoot dry weight yield from interim and final coriander harvests of VP plots in response to N available to 30cm depth of soil (error bars indicate standard error which, in some cases, are obscured by the size of the data point)*

**Table 7.** Coriander harvest maximum fresh weight yield from each N response experiment

| Location | Drilling date | Fresh weight yield (t/ha of cropped area) | Days from drilling to final harvest |
|---|---|---|---|
| WHRI | 21/05/09 | 48.9 | 49 |
| | 23/07/09 | 15.6 | 40 |
| | 11/08/09 | 30.1 | 49 |
| VP | 17/06/09 | 41.3 | 74 |
| | 11/08/09 | 18.3 | 58 |

*Bunch quality at harvest*

Bunches sampled for shelf life evaluation were assessed prior to storage for leaf quality as indicated by SPAD measurements of leaf greenness. For all trials at WHRI, SPAD measurement increased with increase in N (Figure 8) with the greatest differences between treatments associated with the earliest trial drilled (i.e. 21/05/09). These differences are further illustrated in Figure 9 which compares bunches for all treatments at the start of shelf life evaluations. Separation of treatment averages suggests that rates of applied N above 110 kg/ha (i.e. available N of 131-154 kg/ha) produced no further benefits in terms of depth of green colour (i.e. increase in SPAD value).

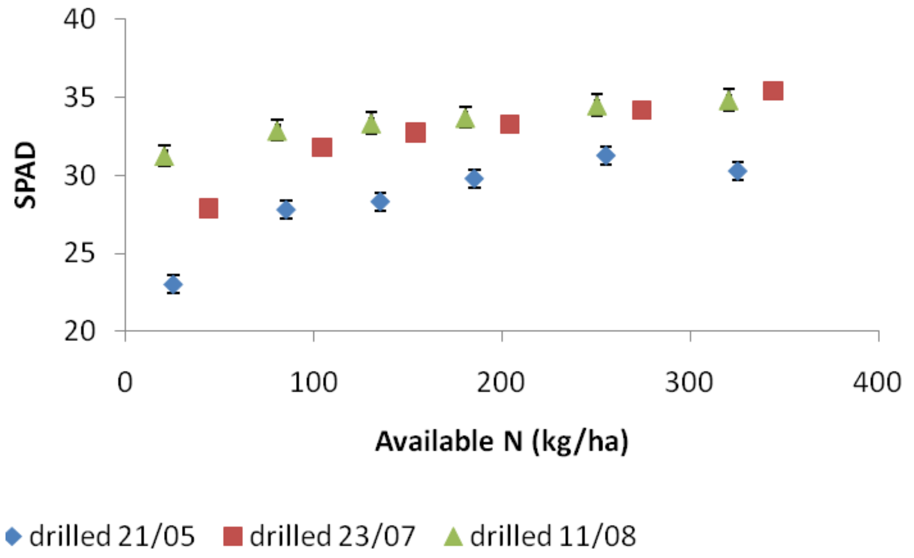


**Figure 8.** *Leaf greenness of bunches at final coriander harvest (error bars indicate standard error which, in some cases, are obscured by the size of the data point)*

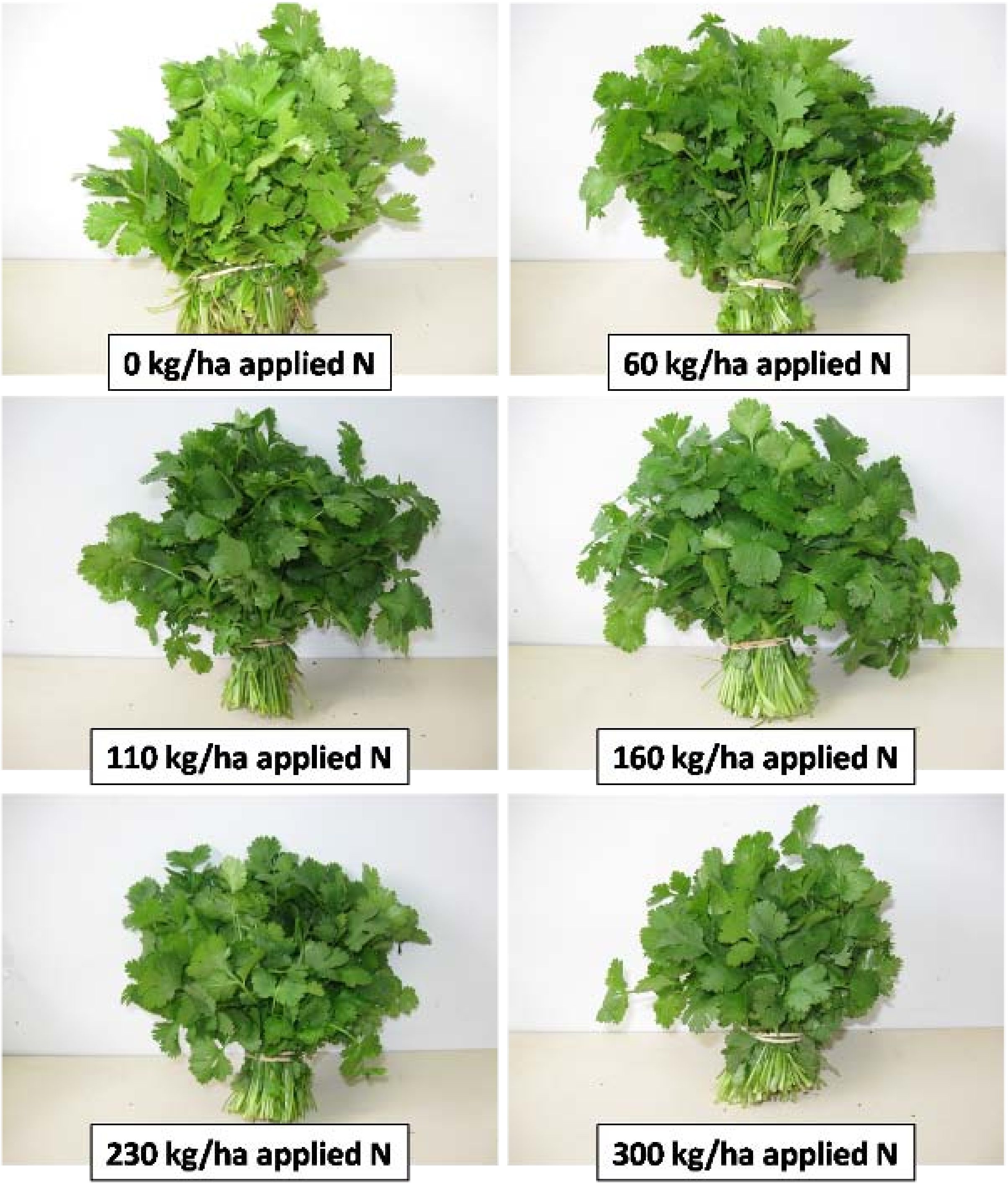


**Figure 9.** Comparison of bunches of coriander at the start of shelf life from the range of applied N treatments (batch drilled 23/07/09)

*Shoot mineral N content:*

Shoot samples from WHRI plots were analysed for mineral content. Data for shoot nitrogen and potassium content were formally analysed using ANOVA.

Shoot nitrogen content was analysed as both total N and $NO_3$-N in order to calculate the organic N content (i.e. total minus $NO_3$-N). In the WHRI trials (Figure 10), shoot organic N content increased with increase in available N, with significant differences found between treatments from all sample dates and drillings except the first interim sample taken from the last trial (i.e. drilled 11/08/09). It is clear from the trial drilled on 21/05/09 that shoot organic N content decreased as plants matured (from 4.0-4.8 % for the earliest sample taken to 1.3-3.4 % at final harvest) and that response to available N was also greater as plants matured, largely because of the reduction in organic N content of plants grown at lower rates of available N. A similar trend is also apparent for the trial drilled on 11/08/09. For the trial drilled on 23/07/09 however shoot organic N content was similar for both the first and final samples with only the 0 rate of applied N (44 kg/ha available N) being appreciably lower for the final sample compared with the first interim sample. This middle drilling date was also associated with higher levels of background N (at 44 kg/ha) compared with the first and last drillings (at 20-25 kg/ha N) and potentially had greater soil N mineralisation during the trial.

Differences in shoot nitrate content would be expected to indicate where surplus N was available (‘luxury feeding’) (Fig. 11). Overall, the highest shoot nitrate content was associated with the latest samples analysed (i.e. final harvest samples) and also from treatments with the highest levels of available N. Shoot nitrate content was also comparable for analogous sample types (i.e. interim 1, interim 2, or final) for the three trials drilled (i.e. for production over the period 21/05/09 to 29/09/09).

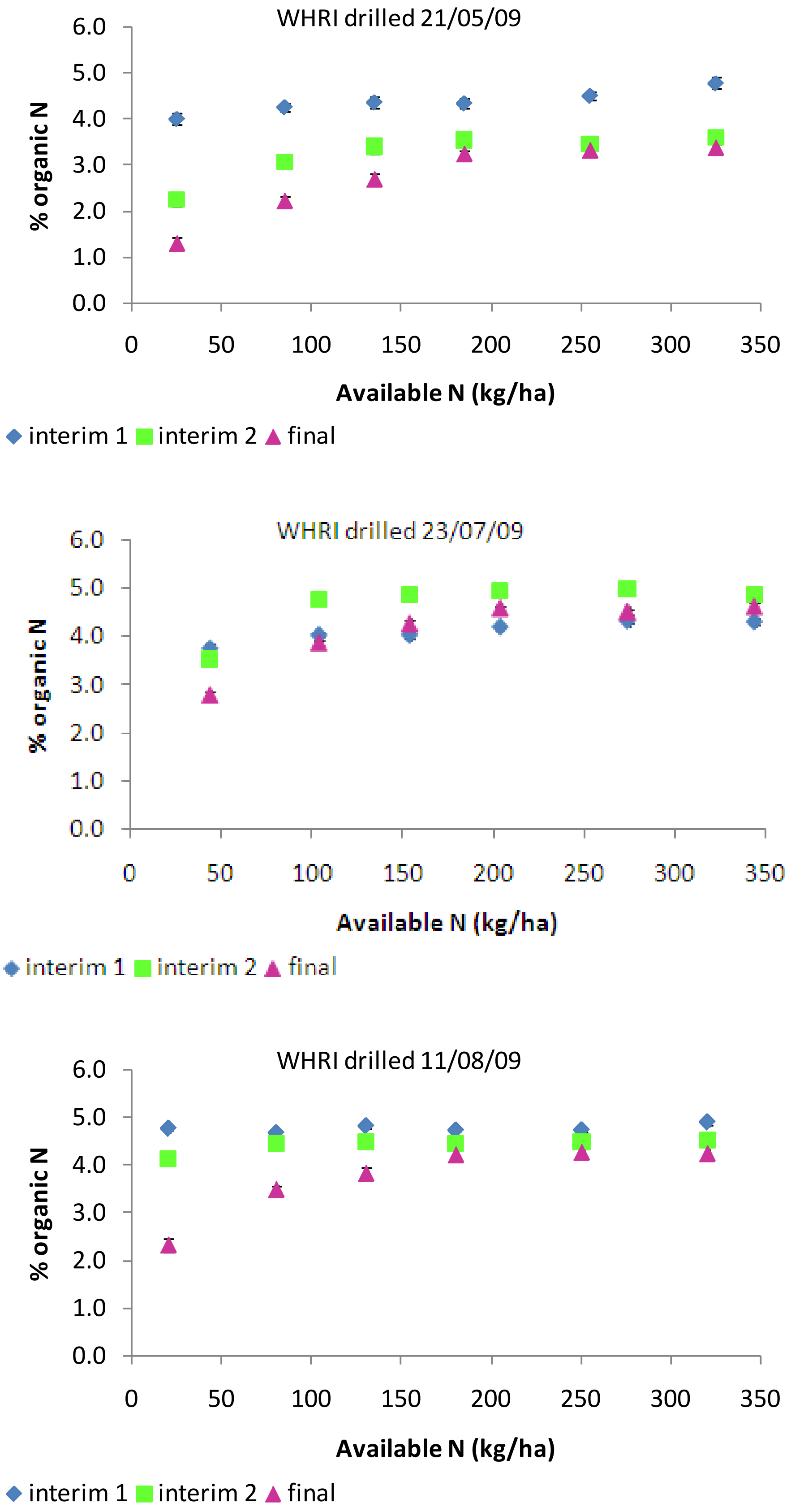


**Figure 10.** *Shoot organic N content from interim and final coriander harvests of WHRI plots (error bars indicate standard error which, in some cases, are obscured by the size of the data point)*

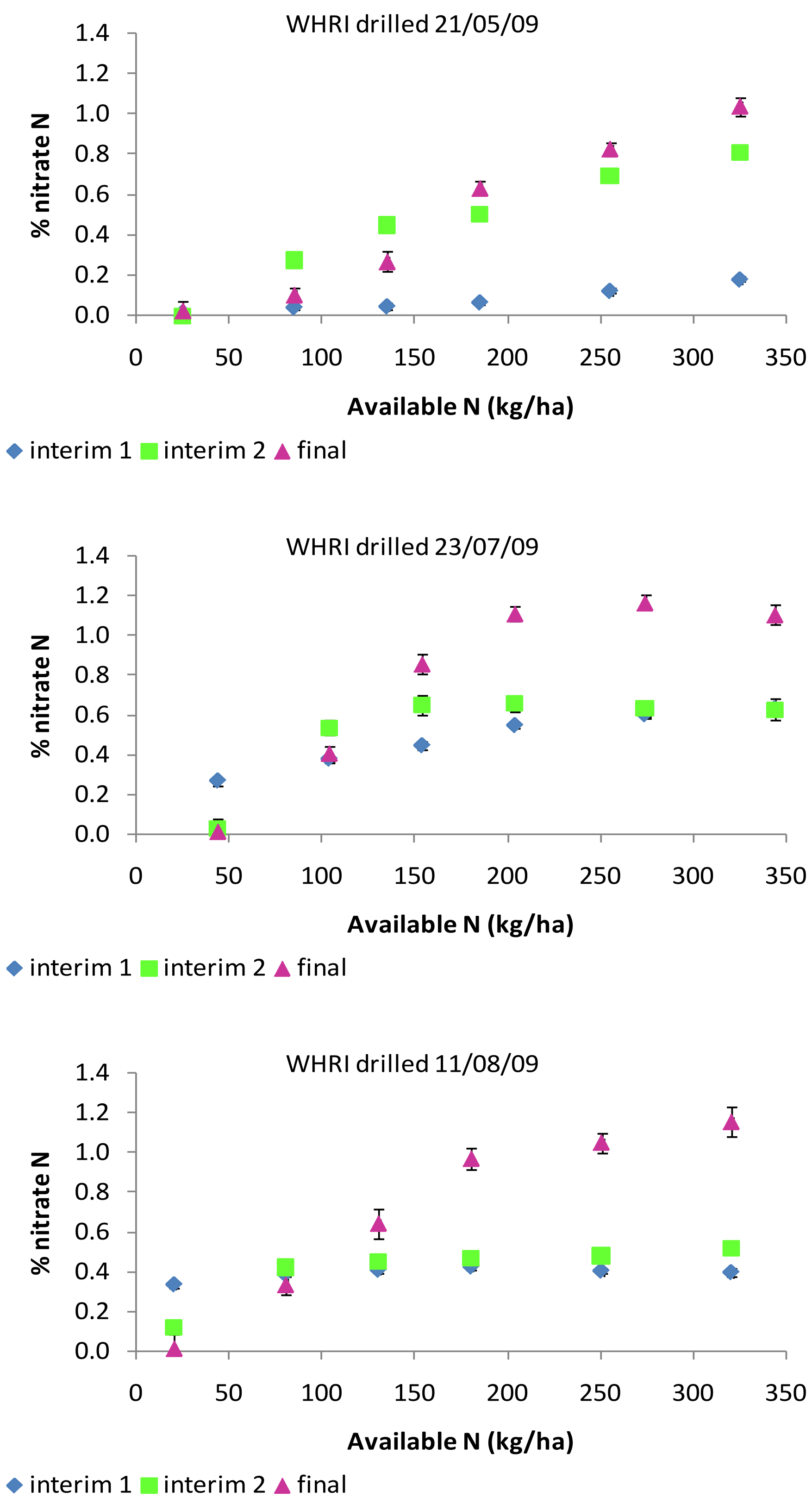


**Figure 11.** *Shoot mineral N content from interim and final coriander harvests of WHRI plots (error bars indicate standard error which, in some cases, are obscured by the size of the data point)*

Plants from the VP plots treated with the low, middle and highest rates of applied N were also analysed for shoot nutrient content. Organic N content had a similar response to available N as described for the WHRI trials described above (Fig. 12). That is % organic N was lower for later samples where availability of N was lower. In general at VP, rates of available N had no impact on % organic N at rates above the 0 applied N treatment.

Shoot organic N content was comparable between plants grown at similar levels of available N at WHRI and VP. For example for the first trial, shoot organic N content at final harvest was 3.3% at WHRI and 3.7% at VP for a rate of available N of around 250 kg/ha.

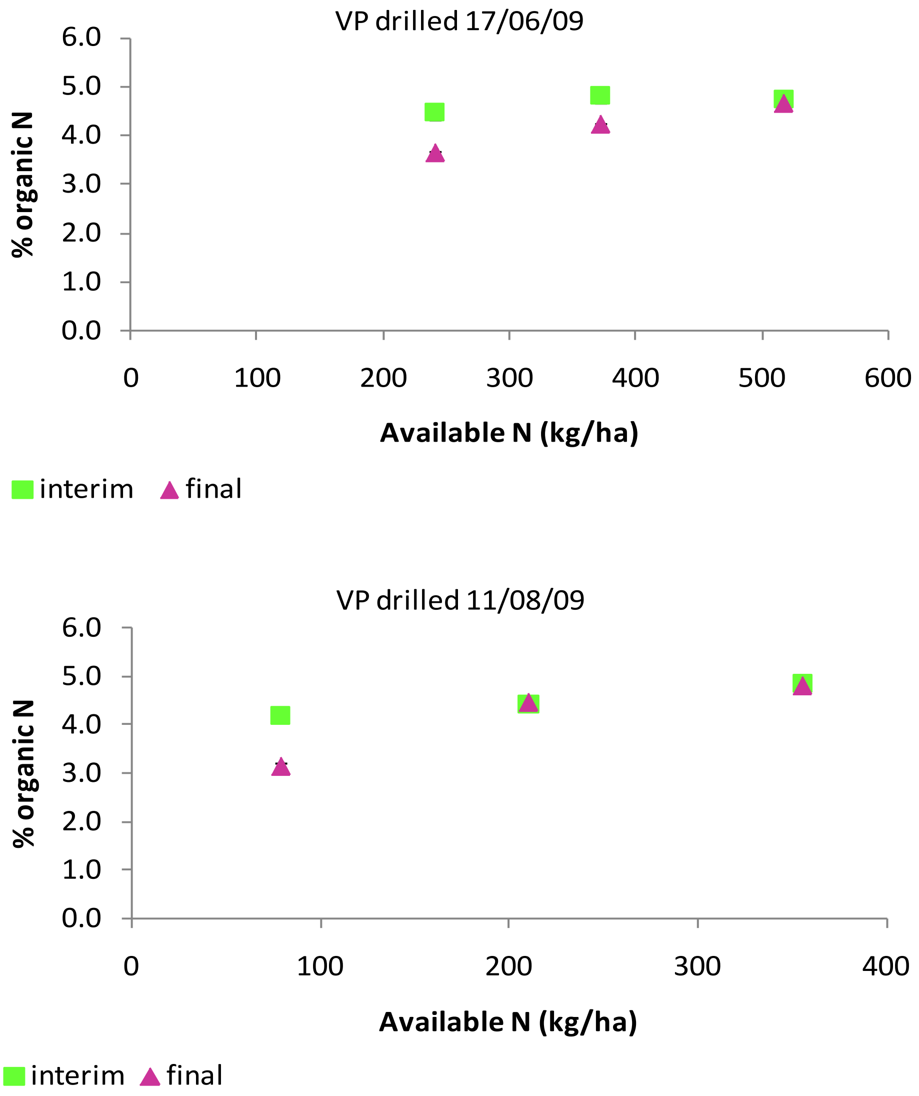
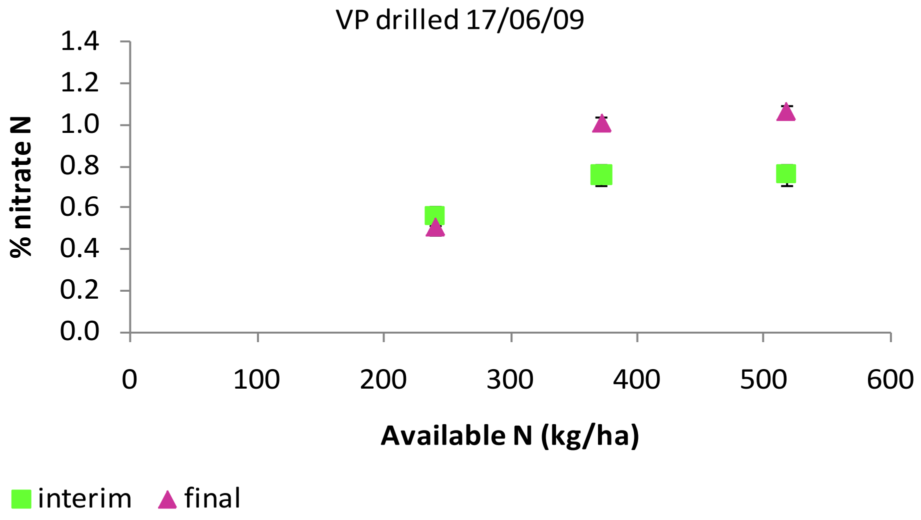


**Figure 12.** *Shoot organic N content from interim and final coriander harvests of VP plots (error bars indicate standard error which, in some cases, are obscured by the size of the data point)*

Nitrate N content was again higher for the later samples taken than the earlier ones with differences between treatments also greater for the more mature plants which would have had more opportunity to accumulate N (Figure 13). As for organic N, % leaf nitrate N content for the earliest crop drilled was comparable between WHRI and VP trials where plants had comparable levels of available N, e.g. at available N around 350 kg/ha, VP plants had 1.02% nitrate N at final harvest and WHRI plants had 1.04% nitrate N.



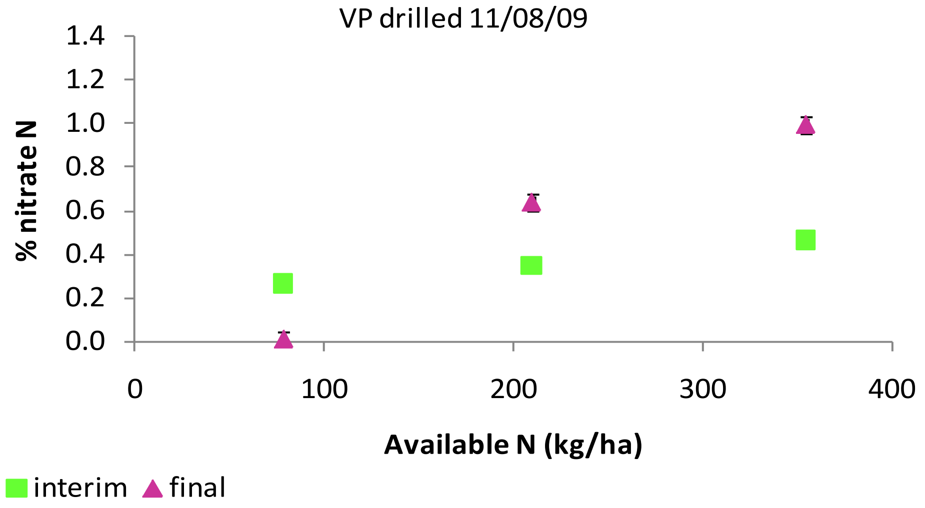


**Figure 13.** *Shoot nitrate N content from interim and final coriander harvests of WHRI plots (error bars indicate standard error which, in some cases, are obscured by the size of the data point)*

Data for the remaining mineral elements have been compiled into summary tables which indicate minimum and maximum concentration for each element for the rate of applied N which produced maximum yield at each growth stage. This data (summarised in Appendix 1) will provide a useful reference source for growers carrying out their own shoot analysis in that it represents crops from two different growing environments (VP and WHRI), from three drilling dates spanning a typical season in the UK. The ranges of shoot N concentrations for treatments producing optimum growth at each sample date (i.e. interim 1 and 2 as well as final harvest) are summarised in Table 8. These ranges do vary with trial site, with the VP trials producing higher shoot N concentration overall than the WHRI trials which reflects the differences in background N levels for the first trial sown, but these differences were not apparent between the last trial sown at each site. Since the response to N was greater in WHRI trials, the data associated with these trials may be a better indicator of suitable shoot N status for optimising growth, with the % total N figure most likely to represent data produced by standard leaf analysis. Total N and organic N content decreased with age of the crop whereas mineral ($NO_3$-N) content either remained at a similar level or increased as the crop matured. Data from the literature falls within the ranges given in Table 8. Hooper and Dennis (2001) for example gives a range of 3.1 to 5.8% total N for several samples taken over a two year period in Australia with an average of 4.1% total N for these samples. Broadley *et al.*, (2004) found 5.73% total N and 4.24% for coriander grown hydroponically and fed with a feed designed to provide sufficient availability of all nutrient elements.

### *Nitrogen offtake*

Amount of N expected to be removed at harvest (i.e. within all plant material removed during harvesting) may be calculated in order to indicate appropriate rates of fertiliser required to balance this net uptake. This has been estimated from the experimental data by multiplying average dry weight yield by organic N content (since mineral N content suggests luxury feeding which should be managed to a minimum); these data are summarised in Table 8. Since the yield data is expressed on a cropped area basis, these data could be adjusted to 75% of the given figures to account for unproductive area (wheeling / headland) which equates to rates of N offtake between 8 to 99 kg N per ha of total field area (i.e. 11 and 132 kg N per ha cropped area as given in Table 9). Since the yields produced in the earliest trials at VP and WHRI are considered to be high by commercial estimates (communication in BHTA technical meeting 03/03/09), it may be sensible to base general estimates of N offtake on the later drilled trials which would suggest N offtake per total field area at 8 to 56 kg/ha N. Looking more specifically at rates of available N producing maximum yield, N offtake (per total field area) for a well grown crop would be expected to be 39-48 kg/ha for trials drilled 23/07/09 and 11/08/08 at WHRI.

While fertiliser rates need to balance expected crop demand, they must also consider the impact of N concentration in the root zone during production. That is, whilst total requirement for production can be made available to the crop as fertiliser, if there is insufficient N for uptake at any point in time (e.g. if roots and available N are not in the same place, due for example to insufficient root development at earlier stages of growth) there may still be a restriction in plant growth. Hence fertiliser recommendations may not match exactly with the predicted offtake values.

**Table 8.** Indication of coriander leaf N content based on treatments producing maximum growth from each trial drilled

| **Shoot N content for plots producing maximum growth:** | | | |
|---|---|---|---|
| sample / drilling | % Organic N | % $NO_3$-N | % Total N |
| WHRI | | | |
| interim 1 sample (at 4-5 true leaves) | | | |
| drilled 21/05/09 | 4.5-5.0 | 0.16-0.20 | 4.7-5.2 |
| drilled 23/07/09 | 4.8-5.1 | 0.50-0.76 | 5.5-5.7 |
| drilled 11/08/09 | 4.0-4.8 | 0.31-0.52 | 4.3-5.3 |
| interim 2 sample (at 7-9 true leaves) | | | |
| drilled 21/05/09 | 3.3-4.0 | 0.74-0.86 | 4.2-4.8 |
| drilled 23/07/09 | 4.0-4.2 | 0.43-0.47 | 4.4-4.7 |
| drilled 11/08/09 | 4.4-5.0 | 0.28-0.44 | 4.8-5.4 |
| Final harvest sample | | | |
| drilled 21/05/09 | 2.7-3.7 | 0.58-1.06 | 3.4-4.7 |
| drilled 23/07/09 | 4.1-4.5 | 0.78-0.98 | 4.9-5.3 |
| drilled 11/08/09 | 3.1-4.1 | 0.10-0.74 | 3.2-4.9 |
| VP | | | |
| interim sample (at 7-9 true leaves) | | | |
| drilled 17/06/09 | 4.0-5.0 | 0.69-1.07 | 4.9-5.8 |
| drilled 11/08/09 | 4.4-4.5 | 0.34-0.36 | 4.8 |
| Final harvest sample | | | |
| drilled 17/06/09 | 4.0-4.5 | 0.94-1.07 | 4.9-5.6 |
| drilled 11/08/09 | 4.3-4.6 | 0.57-0.71 | 4.9-5.3 |

**Table 9.** Calculated N offtake (kg/ha) by coriander for a range of available N levels and drilling dates at WHRI and VP

| **Available N (kg/ha)** | **Drilling dates** | | | | |
|---|---|---|---|---|---|
| | WHRI trials | | | VP trials | |
| | 21/05/09 | 23/07/09 | 11/08/09 | 17/06/09 | 11/08/09 |
| 20-50 | 27.9 | 11.2 | 30.8 | | |
| 80-100 | 69.1 | 40.1 | 63.7 | | 31.3 |
| 130-150 | 93.8 | 51.8 | 73.3 | | |
| 180-200 | 115.2 | 53.3 | 73.5 | | 40.3 |
| 240-270 | 128.6 | 45.8 | 65.9 | 89.3 | |
| 320-340 | 131.8 | 43.5 | 75.1 | | 59.1 |
| 350-370 | | | | 113.3 | |
| 520 | | | | 120.3 | |

*Estimation of critical N*

In order to determine a general recommendation for coriander N requirements, the data from the more responsive WHRI trials have been collated to generate a critical N curve (Figure 14). Points on the curve are taken from each sample of each trial drilled with the average %N shoot content plotted for the samples representing maximum yield on each occasion against the relevant dry weight yield figure.

This curve may be used to estimate organic N content of a crop of dry weight within the range 0-4 t/ha which may be used to refine N offtake predictions based on local conditions and hence expected yield. Data from VP trials have been plotted on this critical N curve as a credibility check. The lowest data point for the VP trials relates to the crop drilled 11/08/09 and grown without addition N fertiliser (i.e. 0 kg/ha applied N or 79 kg/ha available N). Points below the critical N curve indicate a crop grown with insufficient available N which is sensible for this treatment (i.e. no added N and lower background N or the point labelled VP2 0N on the chart). The highest data point relates to the 276 kg/ha applied N treatment (517 kg/ha available N, labelled VP1 267N on the chart) from the 17/06/09 drilling at VP. As this trial had very high background N it is not surprising to find this point above the critical N curve (indicating higher shoot N content than was required to produce this level of yield).

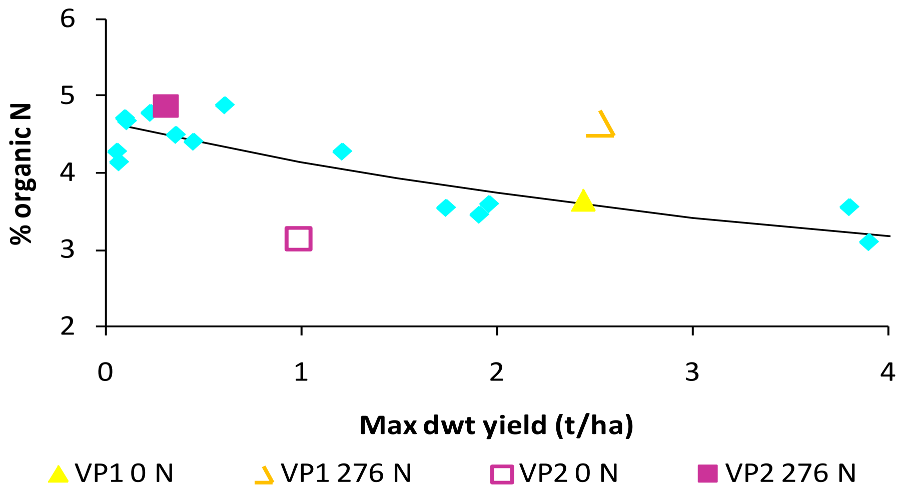


**Figure 14.** Critical N curve for coriander grown in trials at WHRI with points for VP crops plotted as a validation

*Calculation of N fertiliser recommendation*

Taking the data from the critical N curve and using the assumptions noted in Table 10 which are based on the first trial at WHRI with an N offtake of around 130 kg/ha, preliminary recommendations for coriander N requirements have been calculated (Table 11). Whilst yield was high for the first crop it was comparable with the figures produced for the commercial crop and basing the recommendations on later trials risks producing figures that N fertiliser needs to achieve critical concentration of available N and not just balance expected offtake. Further work examining placement of N may further improve the efficiency of N utilization without risking depletion of the critical N concentration in the soil.

**Table 10.** Assumptions used for calculating preliminary fertiliser recommendations for coriander based on WHRI Wellesbourne 3 coriander plantings in 2009

| | | |
|---|---|---|
| Potential Marketable Fresh wt Yield (t/ha) | 48 | 3.84 t/ha DW Max Yield harvested.<br>(95% of crop grown) |
| DM% Marketable | 8.0 | Average DM% first 2 plantings at opt N level. |
| DW Harvest Index | 0.95 | |
| Calculated Total DM (t/ha) | 4.0 | |
| Calculated N Offtake | 129 | Critical N% (organic N) = $a(1+be^{-0.26W})$<br>a = 2.38 and b = 0.959<br>w= total dry matter yield (t/ha) |
| Max Rooting Depth (cm) | 30 | |
| Recovery Fertiliser % | 60 | |
| Mineralisation (kg/ha) | 29.5 | 21st May for 6 weeks |

**Table 11.** Preliminary N fertiliser recommendations (kg/ha) for coriander.

| **SNS Index***<br>(Mineral N (kg/ha) to 90cm) | **0**<br>(50) | **1**<br>(70) | **2**<br>(90) | **3**<br>(110) | **4**<br>(140) | **5**<br>(200) | **6**<br>(250) |
|---|---|---|---|---|---|---|---|
| Proposed rate of N | 140 | 125 | 115 | 105 | 90 | 55 | 30 |

*(*Note: SNS index in the Defra Fertiliser Manual are based on assessments of mineral N to 90 cm depth based on previous crop, soil type and over-winter rainfall. SNS index has to be estimated from measurements of mineral N to 30cm (rooting depth). To use SNS tables, the measurement to 30 cm should be multiplied by 3 to provide the relevant SNS index relevant to coriander).*

### *Coriander response to potassium*

#### *Growth analysis*

Extra K was applied to plots at top dressing stage (i.e. after the first interim sample had been taken). Application of extra K (high K) to plots had no significant influence on yield of the second interim sample. Some significant differences were found for final samples of the trials drilled on 23/07/09 and 11/08/09 but trends are inconsistent suggesting there would be little impact to crop yield as a result of applying extra K at the rate tested here (Fig. 15).

#### *Bunch quality at harvest*

The extra K applied as top dressing had no significant impact on leaf quality, as indicated by leaf greenness determined using a SPAD meter, at final harvest stage (Fig. 16).

#### *Mineral analysis*

The high K treatment had no significant influence over K content in shoot tissues from the second interim sample. By the final sample, when there had been greater opportunity for uptake, the high K treatment had significantly increased % K content of plants grown from the first drilling (21/05/09). Whilst a similar trend was also apparent for plants grown from the two later drillings, this was not statistically significant (Fig. 17).

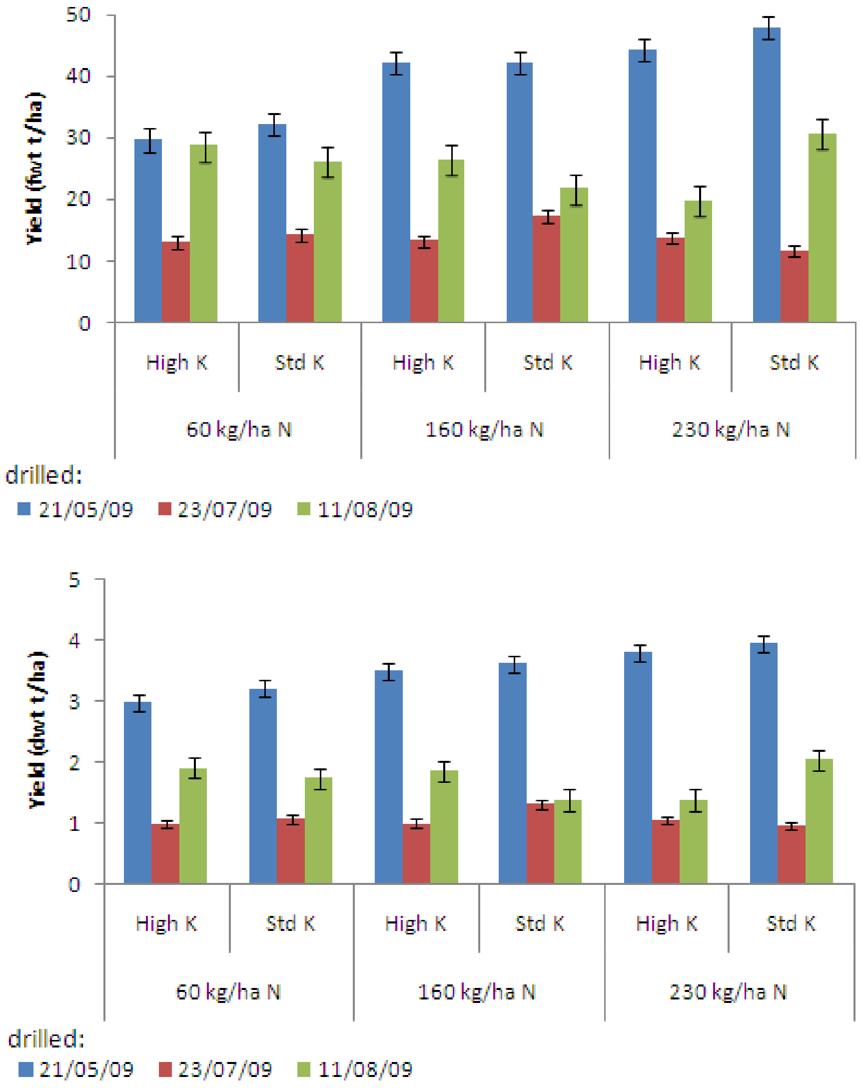


**Figure 15.** *Influence of K (as 166 kg/ha extra K) on final and dry weight coriander grown at 3 rates of N and drilled on three occasions (error bars indicate standard error)*

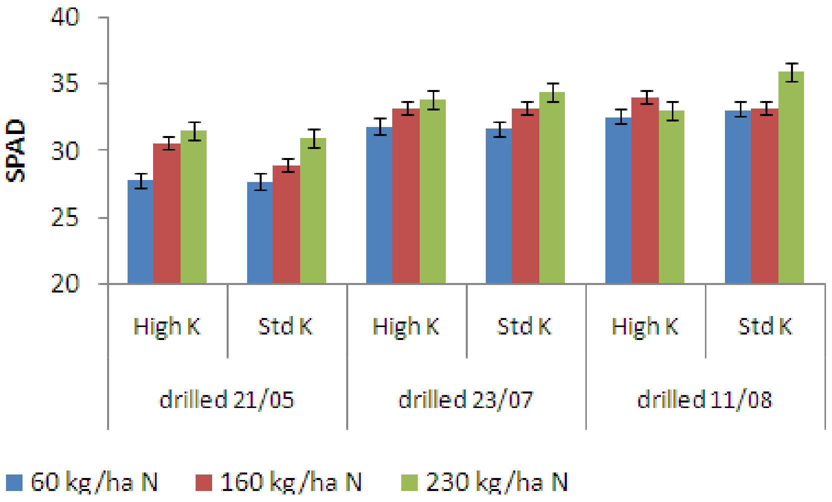


**Figure 16.** *Leaf greenness of coriander bunches at harvest (bars indicate standard error)*

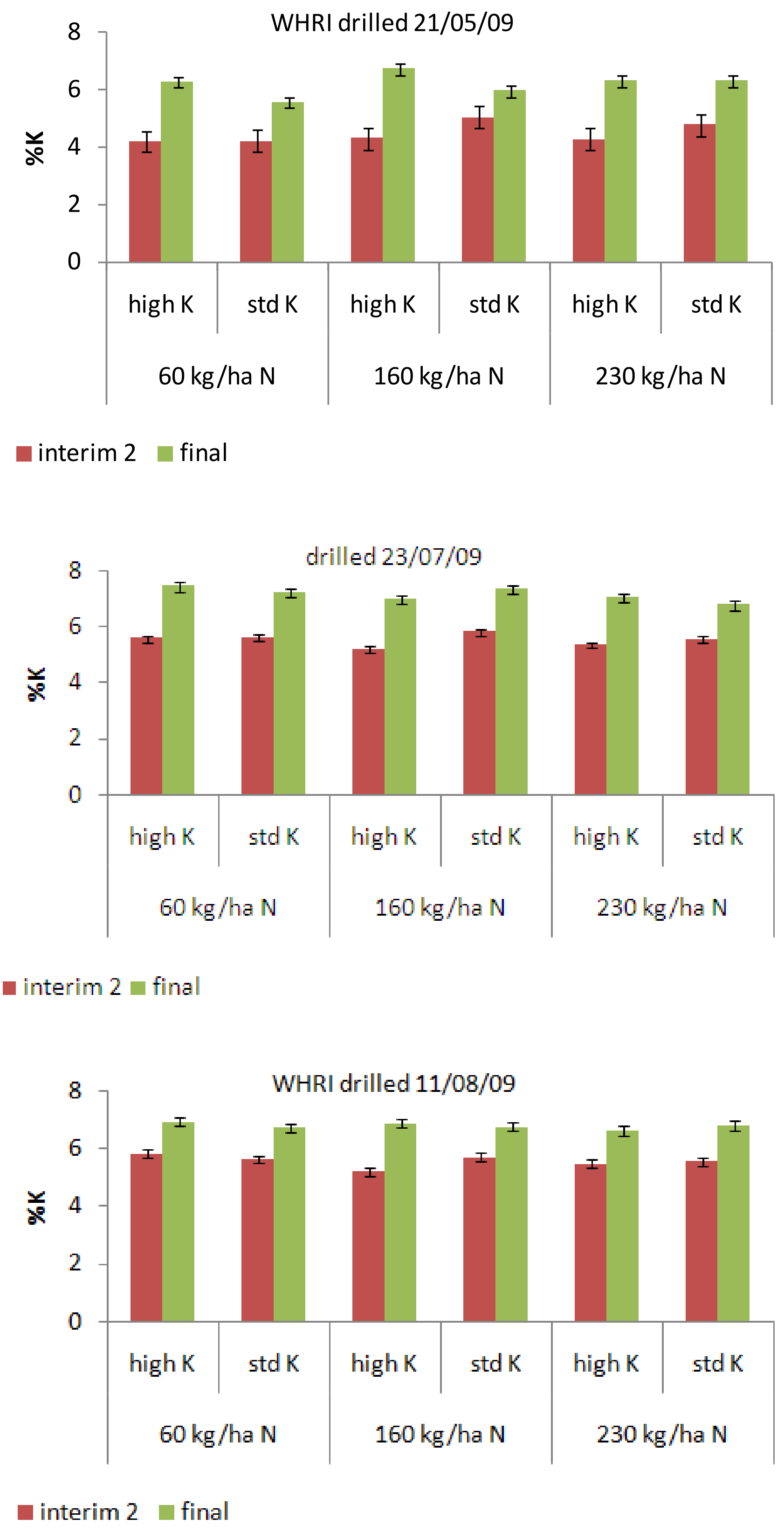


**Figure 17.** *The influence of application of high fertiliser K on shoot K content of coriander grown at 3 rates of N and drilled on three occasions (error bars indicate standard error)*

*Coriander response to N in Shelf Life*

Whilst shelf life was assessed on several parameters as described under methods, the main factor to change in these assessments was wilting score. Hence these will be the data evaluated to provide the best indicator of change in product quality over time in shelf life.

Wilting score increased over time in shelf life as bunches wilted. The rate of increase from score 0 (no wilting) to score 2 (severe wilting and bunches no longer useable) was significantly influenced by N treatment. The zero applied N (0 N) treatment had the biggest impact on bunch wilting, with a slower rate of wilting associated with this treatment from each of the 3 drilling dates assessed (Figure 18). Unfortunately, the 0 N treatment also had the poorest quality at harvest stage, and hence the bunches that wilted the slowest, also had the lowest SPAD or leaf greenness values (as highlighted previously) which would be expected to have rendered them unmarketable. Smaller differences were also noted between the change in wilting score of bunches grown at higher rates of N, although trends were not consistent across all drilling dates. For the trial sown on 21/05/09, rate of increase in wilting score was higher as amount of N applied increased, although differences were small e.g. there was 3 days difference between the slowest (60 kg/ha applied N) and fastest (230 and 300 kg/ha) applied N treatments. For the trials drilled 23/07/09 and 11/08/09 however whilst the 0 N treatment continued to wilt less rapidly than plots treated with higher rates of N, there were no consistent differences relating loss of turgor to level of N availability above the 0 kg/ha applied N level.

Length of storage time of harvested bunches was assessed as days from harvest to reject stage. Bunches could be rejected by reaching the maximum score for any of the qualitative assessments included but in practice, bunches reached the maximum score for wilting before the other qualitative assessments and hence ‘days to wilting’ indicates the length of shelf life assessed for each treatment. On this basis bunches from all drilling dates had longer shelf life when grown with 0 applied N (i.e. equivalent to 25-44 kg/ha available N) than any of the higher rates of N assessed. In fact bunches grown at 0 applied N reached the stage of rejection through excessive wilting 11- 18 days later than bunches grown at higher rates of N for the first two drillings (Figure 19). Bunches from the 0 N plots drilled on 11/08 did not last so well in shelf life compared with the earlier drillings but were still viable in shelf life 5-8 days longer than plants grown at higher rates of N. For the first trial drilled, coriander grown at the 60 kg/ha rate of applied N also had a slightly longer shelf life than coriander grown with applied N at 110 kg/ha and above.

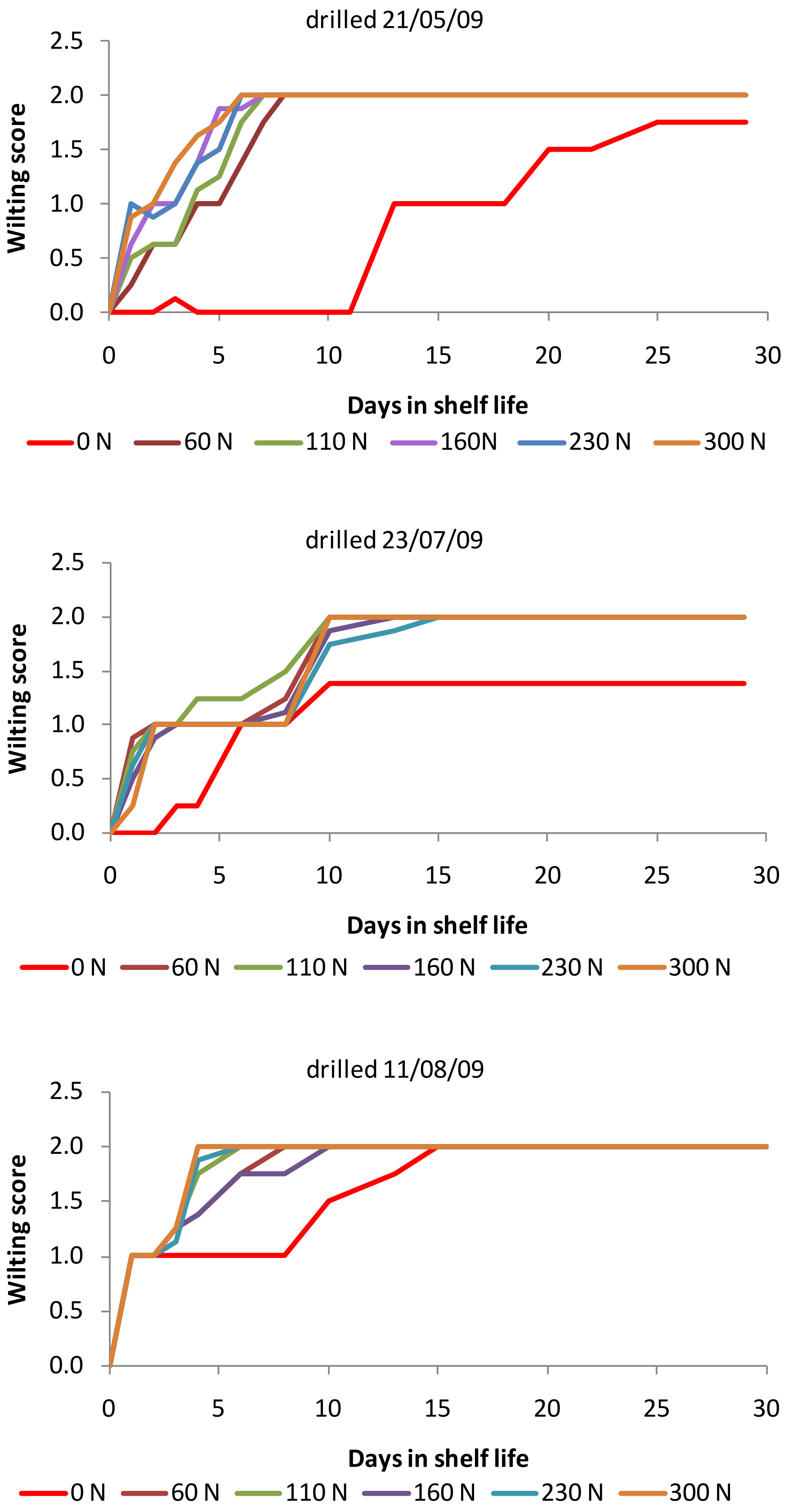


**Figure 18.** *Change in wilting score during shelf life for bunches of coriander grown at a range of applied N levels.*

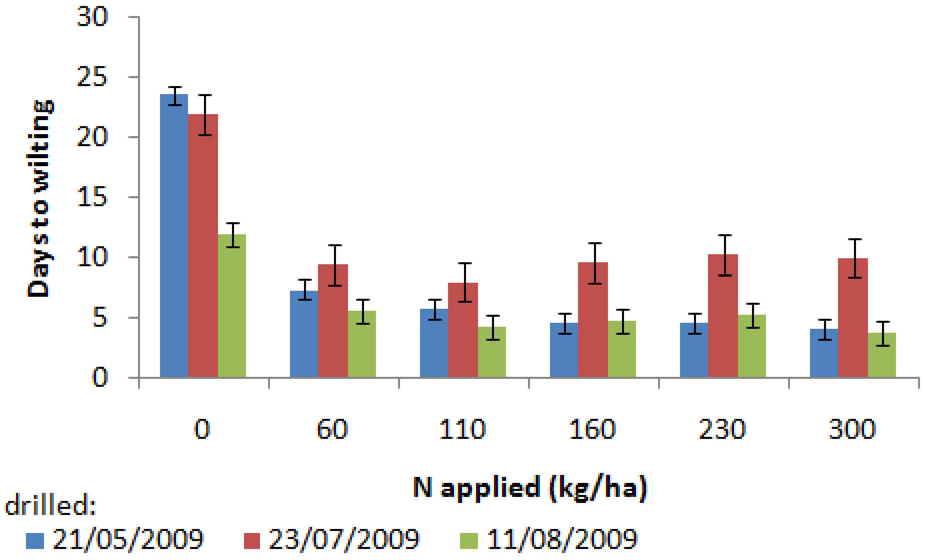


**Figure 19.** *Length of shelf life based on time to wilting for bunches of coriander grown at different rates of applied N (error bars represent standard errors).*

*Coriander response to K in Shelf Life*

As illustrated by the data for time to wilting (Figure 20), the application of a K top dressing had no significant influence of bunch shelf life for the three sowing dates tested, regardless of the rate of K it was combined with.

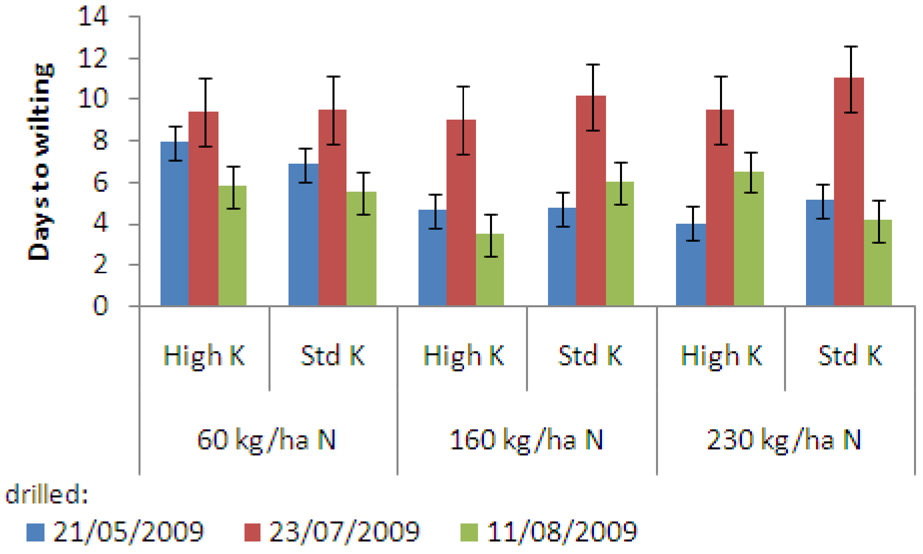


**Figure 20.** *Length of shelf life based on time to wilting for bunches of coriander top dressed with extra K and grown at different rates of applied N (error bars represent standard errors)*

*Preliminary investigation of the effects of NaCl on coriander shelf life*

As K did not appear to influence product shelf life of the first trial of coriander sown at WHRI, some informal investigations were added on to the trial. These consisted of three plots in the guard area at the end of each of the three beds of plots. These additional plots were 1.5m in length and were not replicated; hence the data produced must be treated as preliminary at best. NaCl was applied to these areas at the equivalent of 0, 250 and 500 kg/ha NaCl. This design was planned to provide either equivalent moles of Na to the high K treatment of the main trial for the 250 kg/ha rate of NaCl or double the moles of Na to the high K treatment of the main trial for the 500 kg/ha rate of NaCl.

These treatments were repeated on the crops drilled on 23/07/09 and 11/08/09. N was applied at 160 kg/ha to all three plots and bunches were harvested and assessed for shelf life as described for the main trial.

As with the main trial, changes in wilting were the predominant factor influencing store life of coriander treated with NaCl. Bunches appeared to wilt soonest when grown without NaCl (0 NaCl treatment) and latest when treated with the highest rate of NaCl from both drilling dates assessed (Figure 21). The size of differences was 2 to 3 days between treatments drilled on 23/07/09 and 1 to 5 days between treatments drilled on 11/08/09.

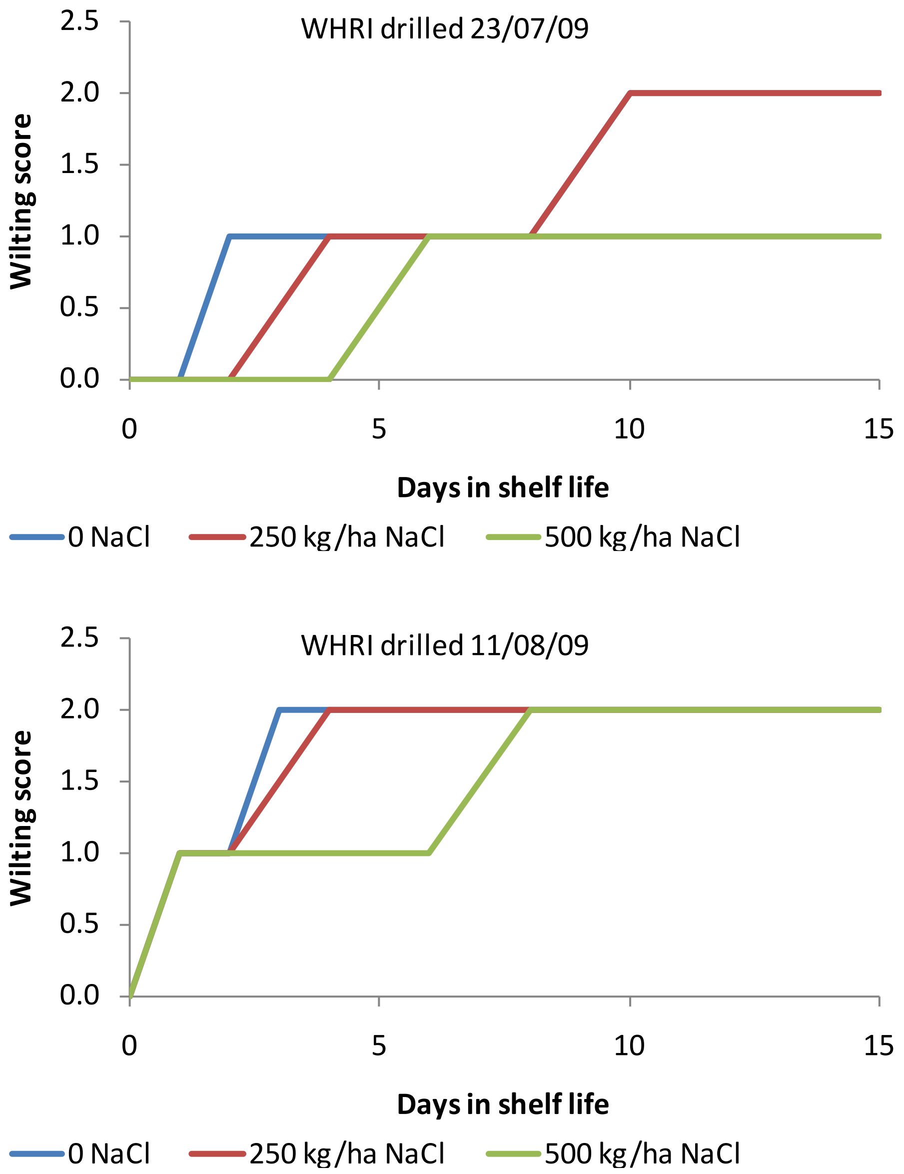


**Figure 21.** *Change in turgor score during shelf life for bunches of coriander top dressed with NaCl*

### ***Mint response to N***

#### *Initial soil mineral status*

The initial N status of trial plots varied with location and plots at VP had higher background N than WHRI plots (Table 12).

**Table 12.** Mineral N levels in 30 cm depth soil cores taken immediately prior to mint planting trials at WHRI and VP and rates of applied N in May 2009

| **WHRI** | | | | | | |
|---|---|---|---|---|---|---|
| **Rate of N applied (kg/ha)** | **0** | **20** | **37** | **53** | **77** | **100** |
| **Available N (kg/ha)** | **29** | **49** | **65** | **83** | **105** | **129** |
| **VP** | | | | | | |
| **Rate of N applied (kg/ha)** | **0** | **52** | **131** | **204** | **276** | |
| **Available N (kg/ha)** | **48** | **100** | **179** | **252** | **324** | |

Available N was calculated by adding N applied as fertiliser to the N assumed to be available from residual levels within the soil to the estimated rooting depth for the crop (Table 13). To convert the mineral analysis data (expressed as µg/g) for each initial sample into kg/ha of soil the following calculation was used:

$$\text{kg/ha N from soil} = \frac{\text{(soil bulk density x depth of sample)}}{10} \text{ x total N in sample (µg/g).}$$

Where bulk density was assumed to be 1.33 and rooting depth was within the first 30cm of the soil, since majority of roots were 5-30cm from the surface of the soil with the deepest root depth estimated at 45 cm at the end of the first season (05/10/09). In the July of the second season, the deepest root depth was estimated at 53 cm, although the majority of roots were 25-30 cm from the soil surface. Whilst these figures do not take account of N mineralised during the year, they do indicate how the two trial sites might be compared by accounting for original N status.

**Table 13.** Available N (kg/ha) in different mint N treatments at WHRI and VP, calculated from mineral analysis of the 0-30cm soil samples and the applied N fertiliser, on different dates in Year 1 and 2. N was applied on each of the dates at the rates shown, except at WHRI on 14.07.09 and 10.03.10 when 68% of the full rate was applied.

| **WHRI** | **Rate of N applied (kg/ha)** | | | | | |
|---|---|---|---|---|---|---|
| Date | 0 | 60 | 110 | 160 | 230 | 300 |
| Year 1 | | | | | | |
| 14.07.09 | 29 | 69 | 102 | 136 | 182 | 229 |
| Year 2 | | | | | | |
| 10.03.10 | 6 | 32 | 51 | 78 | 178 | 236 |
| 18.05.10 | 4 | 65 | 118 | 172 | 246 | 352 |
| 19.07.10 | 5 | 64 | 122 | 283 | 297 | 446 |

| **VP** | **Rate of N applied (kg/ha)** | | | | |
|---|---|---|---|---|---|
| Date | 0 | 52 | 131 | 204 | 276 |
| Year 1 | | | | | |
| 07.05.2009 | 48 | 100 | 179 | 252 | 324 |

*Growth analysis*

The influence of available N on yield in the first season varied with site. At WHRI, the dry weight yield of stems removed for topping (1st and 2nd cuts) in 2009 was significantly influenced by rate of available N with the overall trend of dry weight yield increasing with rate of available N up to the 129 kg/ha levels of available N (100 kg/ha applied N). For the 3rd cut, yield increased with level of available N up to the maximum 229 kg/ha levels of available N (i.e. 200 kg/ha applied N) (Fig. 22). When the end of year 1 yield is examined in its separate components (tops and bases, Fig. 23) it is clear that both parts of the crop responded similarly to available N and hence followed the trend of increasing dry weight as level of available N increased as previously described for total dry weight. It is apparent that at lower rates of N (up to 129 kg/ha available N), there was proportionally more ‘base’ than ‘tops’ whereas at higher rates of N dry weight was split more evenly between the two portions harvested.

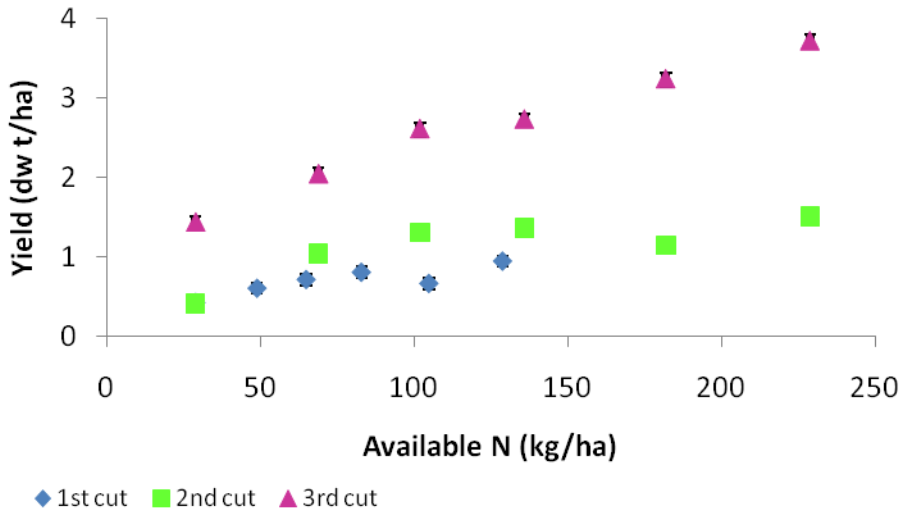


**Figure 22.** *Response of mint at WHRI to available N during year 1 from two topping samples and one end of season sample (error bars indicate standard error)*

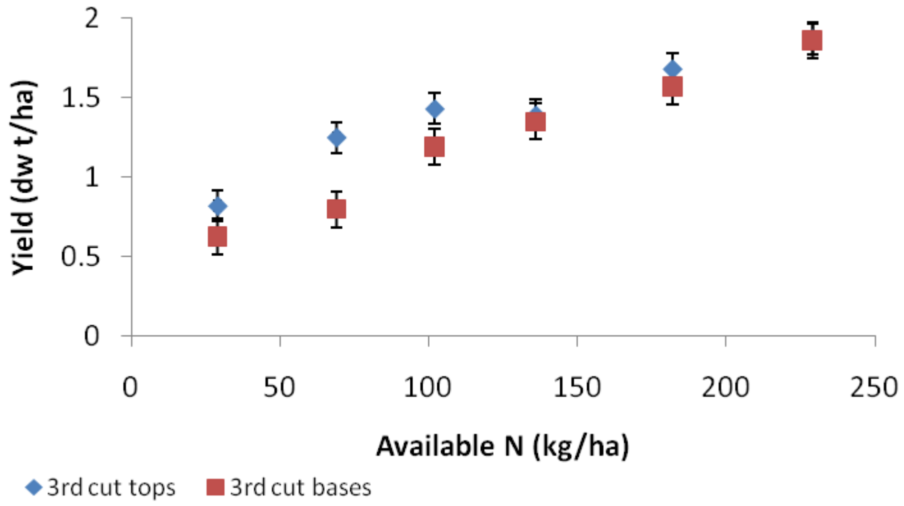


**Figure 23.** *Response of mint at WHRI to available N during year 1 from end of season sample split into 'tops' and base stems. Error bars indicate standard error*

In year 2, the optimum available N was in the range 178-283 kg/ha for the yield of tops of all three cuts (Fig. 24), although the difference in yield with that achieved at available N of 78-172 kg/ha was very small and only statistically significant for the second and third cuts. As in year 1, the proportion of 'top' to 'base' increased with increasing amounts of available N. The optimum available N for the yield of total shoot weight (tops + bases) and plant bases was lower than for tops only (118-122 kg/ha).

Mint grown in the VP trials was less responsive to applied N, although this lack of response should be treated with caution since the trial at VP did not have true replication or randomization of treatments. Yield of 'bases' from the first topping sample in year 1 had some statistically significant differences, such that yield from the 48-179 kg/ha available N rates was higher than from the higher rates, which is opposite to the trends observed for the WHRI data. Yield of 'tops' was not influenced by rate of N in this first topping sample and there were no further significant differences between treatments for either the second topping sample or the final harvest sample (Fig. 25).

To indicate how performance of the crop compares between the two trial sites, the range of dry weight yield (in Year 1, 1st and 2nd cuts, for tops only since bases were not cut from WHRI plots for these samples) across the N treatments applied is summarised in Table 14. Overall, yields in Year 1 were broadly comparable between the two sites. In Year 1, for the first cut (late June/early July), WHRI plants had higher dry weight yield across the range of available N levels. For the second cut (Late July/early August), VP and WHRI plots were similar other than at the lowest rate of available N. For the final cut in Year 1 (late September/early October), VP plots had higher yield than WHRI plots at lower available N levels but were more comparable at the higher rates tested. In Year 2, WHRI plots produced higher yields than the VP plots in the first and second cuts; no yield data was obtained from VP for the third cut of tops.

**Table 14.** Minimum and maximum dry weight yields (t/ha) from mint tops and bases harvested for a range of available N levels (Year 1, 1st and 2nd cuts, tops only).

| | | WHRI | VP |
|---|---|---|---|
| Year 1 | 1st Cut | 0.43 – 0.95 | 0.28 – 0.41 |
| | 2nd Cut | 0.42 – 1.51 | 1.14 – 1.27 |
| | 3rd Cut | 0.63 – 1.86 | 1.61 – 1.91 |
| Year 2 | 1st Cut | 2.69 – 4.03 | 2.52 – 3.02 |
| | 2nd Cut | 1.33 – 3.81 | 0.94 – 2.04 |
| | 3rd Cut | 1.03 – 2.66 | – |

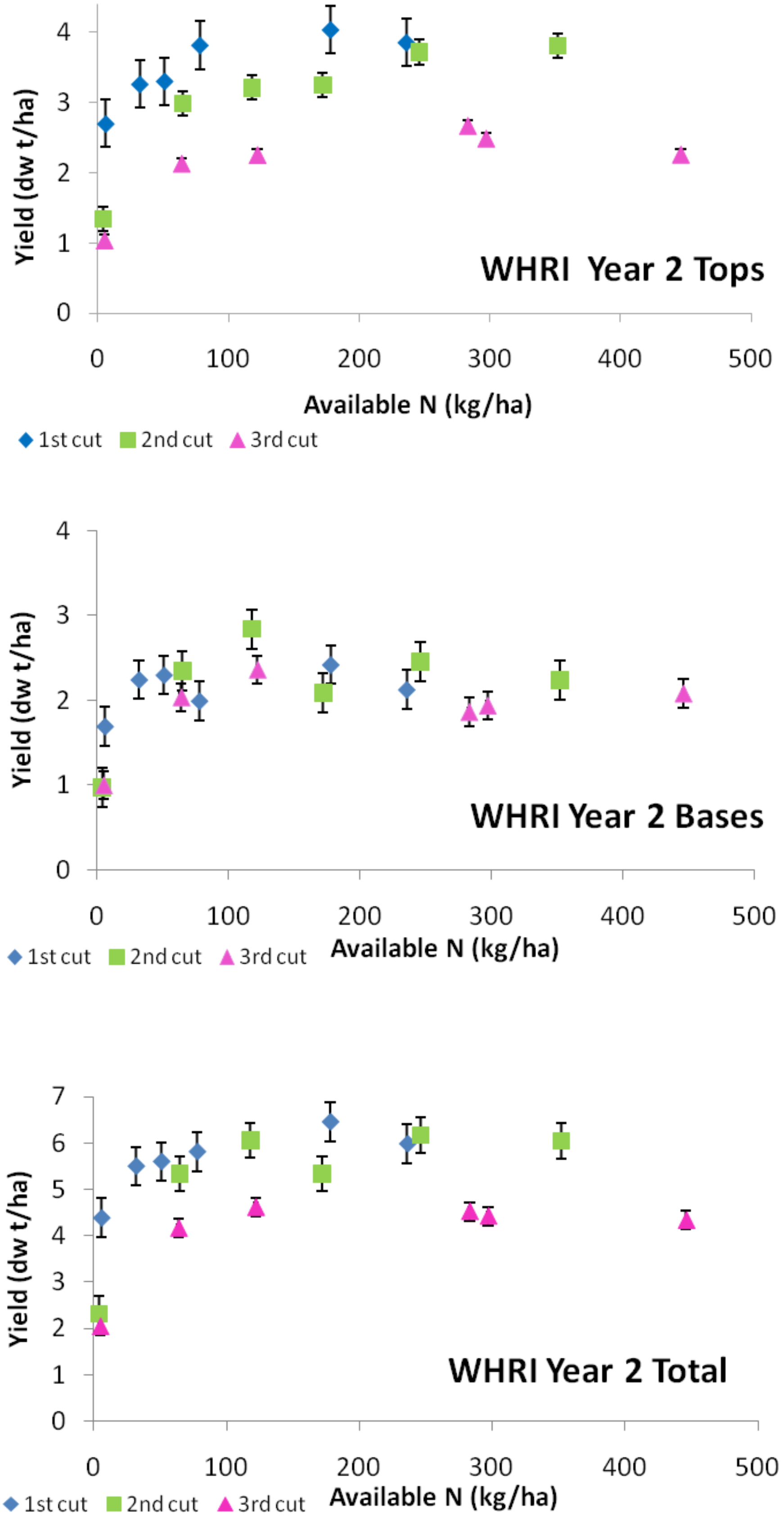


**Figure 24.** *Yield response of mint at WHRI to available N in year 2, split into 'tops' and 'bases' of shoots and also as total shoot weight (error bars indicate standard error).*

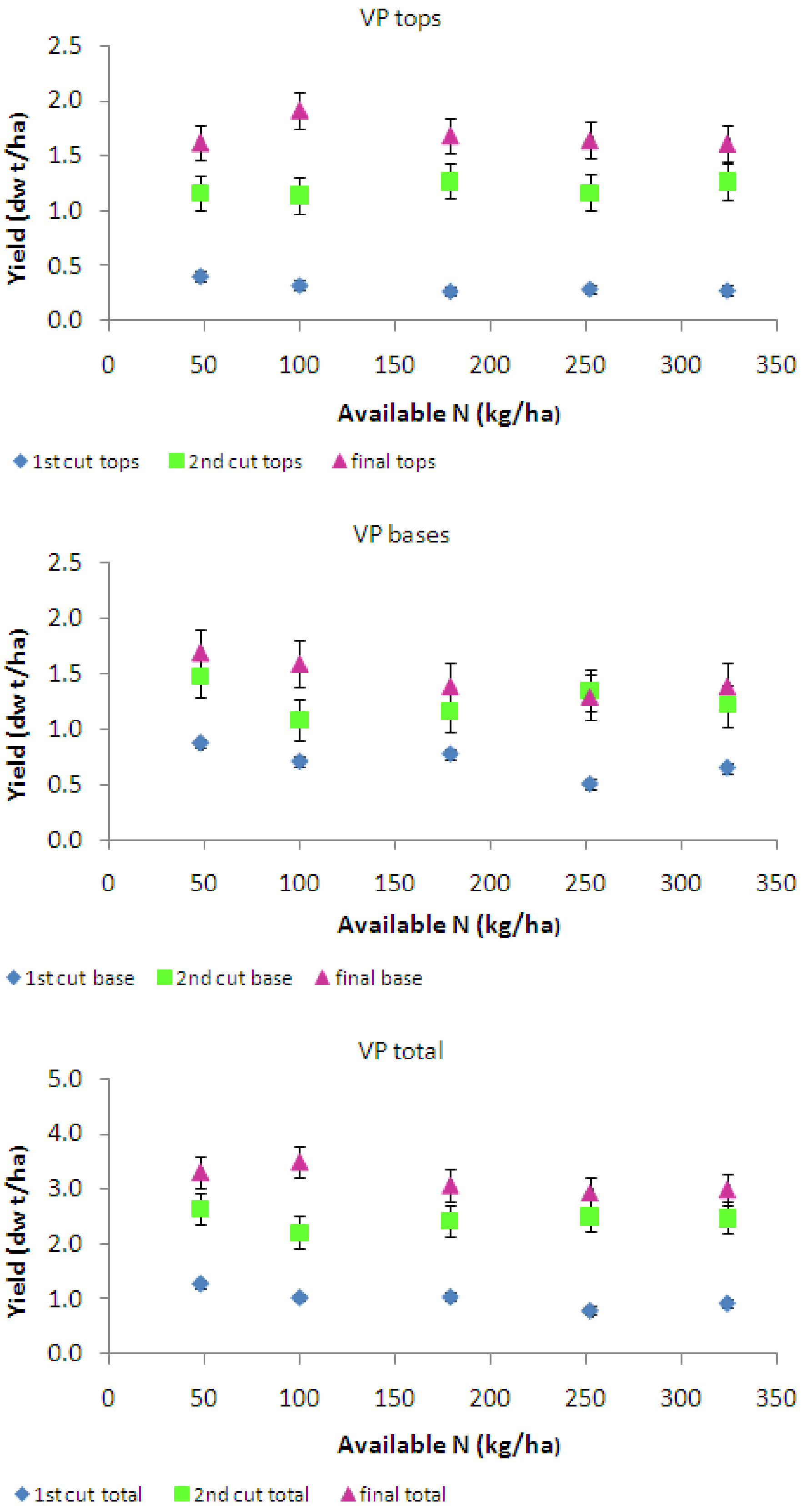


**Figure 25.** *Yield response of mint at VP to available N in year 1, split into 'tops' and bases of stems and also as total shoot weight (error bars indicate standard error)*

*Shoot mineral N content*

In Year 1, shoots removed during the second cut for topping on 06/08/09 at WHRI had the highest % organic N content of the three samples assessed during the season. Organic N content in these shoots significantly increased as level of available N increased (Fig. 26) with the highest level of available N resulting in the highest shoot organic N content at 4.3%. Organic N levels in shoots from the first and final cuts were lower overall (at 2.3-2.8% organic N in shoots from the first cut and 1.9-2.3% in shoots from the final cut) and were not significantly influenced by available N.

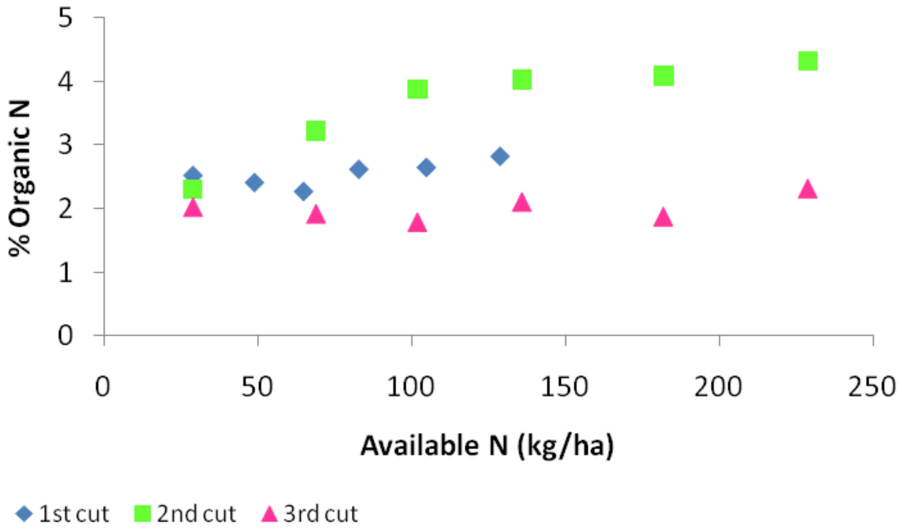


**Figure 26.** *Shoot organic N content from mint shoots harvested for topping and end of year one cutting back of WHRI plots (error bars indicate standard error).*

Shoot material removed for the final cut of 2009 was divided into tops which were suitable for marketing and bases which were not suitable for marketing but removed as the end of season clearing of the bed. Organic N content was higher for the tops (at 1.8-2.3%) compared with the bases (at 0.4-0.8%); as would be expected for less woody material (Figure 27). Available N level did not influence % organic N in either tops or bases removed as part of the final cut from WHRI plots in Year 1. The material removed as bases is likely to be left in place in commercial cropping systems and hence would provide a source of organic N which would be re-introduced to the soil.

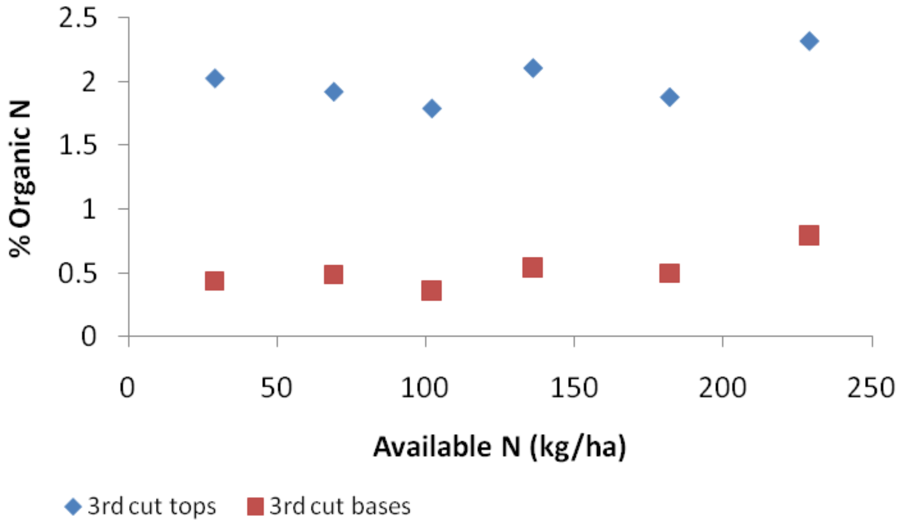


**Figure 27.** *Shoot organic N content from mint shoots harvested at the end of the year 1 cutting back of WHRI plots and separated into tops suitable for marketing and bases cut back to soil level (error bars indicate standard error)*

As with organic N, only nitrate N of shoot material removed through topping WHRI plots during the second cut of the first season had a significant response to available N (Figure 28). Higher % nitrate N content (up to 0.35%) was found as available N increased above 200 kg/ha. Shoots removed for the second cut also had higher % nitrate N content than from the first or final cuts.

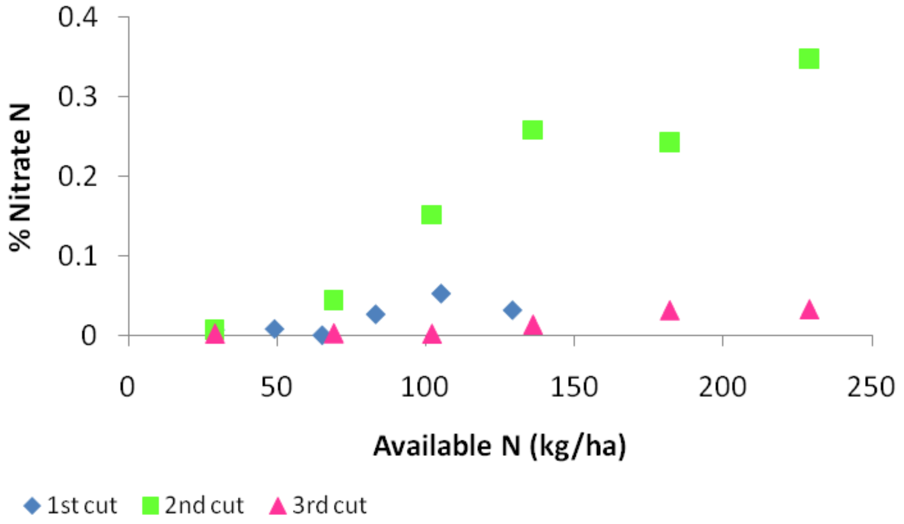
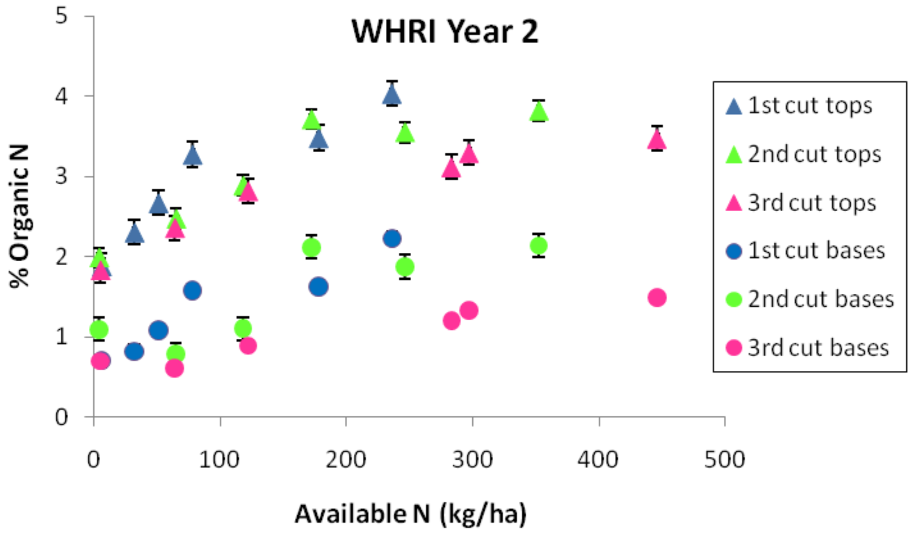


**Figure 28.** *Shoot nitrate N content from mint shoots harvested for topping and end of year 1 cutting back of WHRI plots (error bars indicate standard error)*

In Year 2, organic N reached a maximum at 236 kg/ha available N in the first cut in both tops and bases of shoots. In the second and third cuts, organic N reached a maximum at 122-172 kg/ha available N, and did not increase at higher levels of available N (Fig. 29). Conversely,

% nitrate N continued to increase with increasing levels of available N, and was highest in tops and bases of shoots at the highest level of available N (236-446 kg/ha) (Fig. 29).



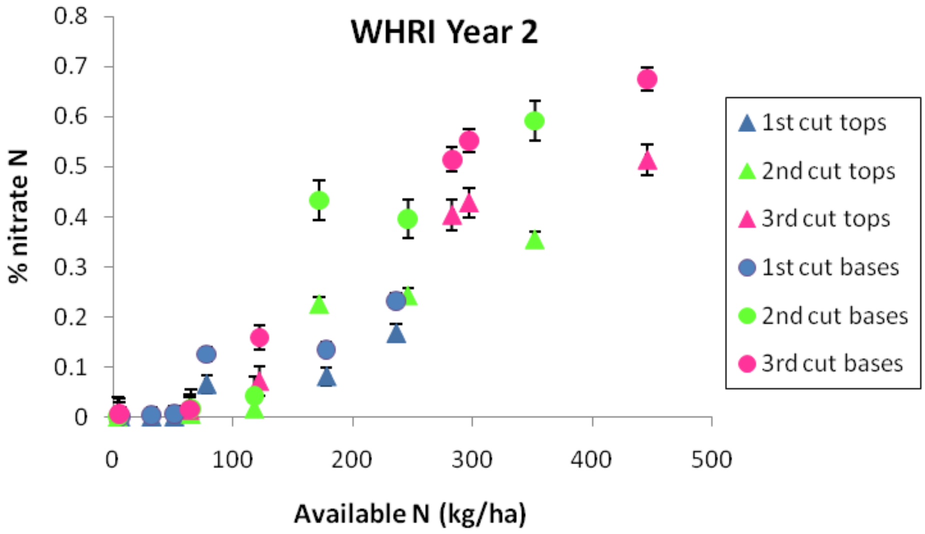
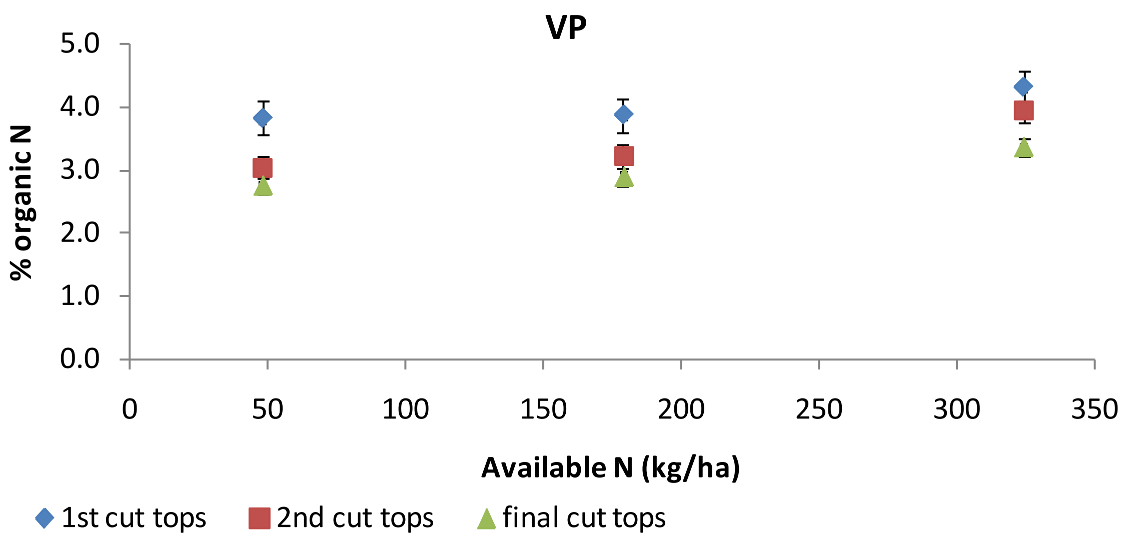


**Figure 29.** *Shoot organic N and nitrate N contents from mint tops and bases of shoots from WHRI plots in year 2 (error bars indicate standard error which in some cases are obscured by the size of the data point).*

In Year 1, whilst dry weight yield of tops removed from VP plots in response to applied N was not influenced by level of available N, % organic N increased slightly (e.g. from 2.77 to 3.35 for the final sample of 2009) as level of available N increased. Percentage organic N in bases (at 1.34 to 3.35%) harvested at each sample date was overall lower than in the tops (at 2.77 to 4.32%); and increased slightly as level of applied N increased for the second and final cuts of the season (Fig. 30).



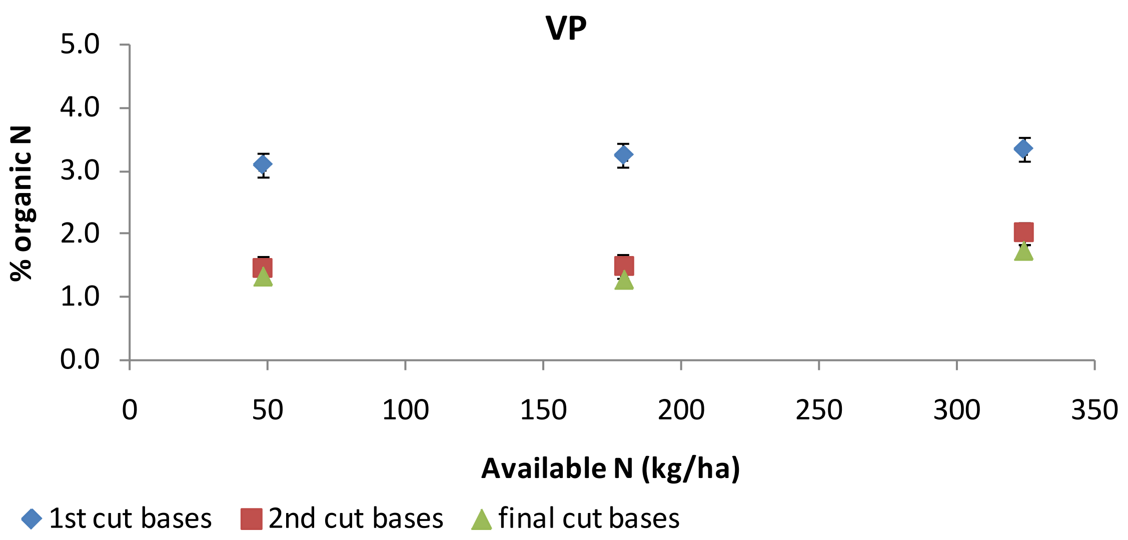


**Figure 30.** *Shoot organic N content from mint shoots harvested for topping and end of the first season cutting back of VP plots separated into tops representing marketable portion of the stem and bases representing residual shoot material cut back to ground level (error bars indicate standard error).*

Shoot nitrate N content in tops and bases harvested from VP plots follow similar trends to those harvested from WHRI tops, i.e. an increase as available N increased, although differences relating to available N level are only significant from the second cut (Fig. 31).

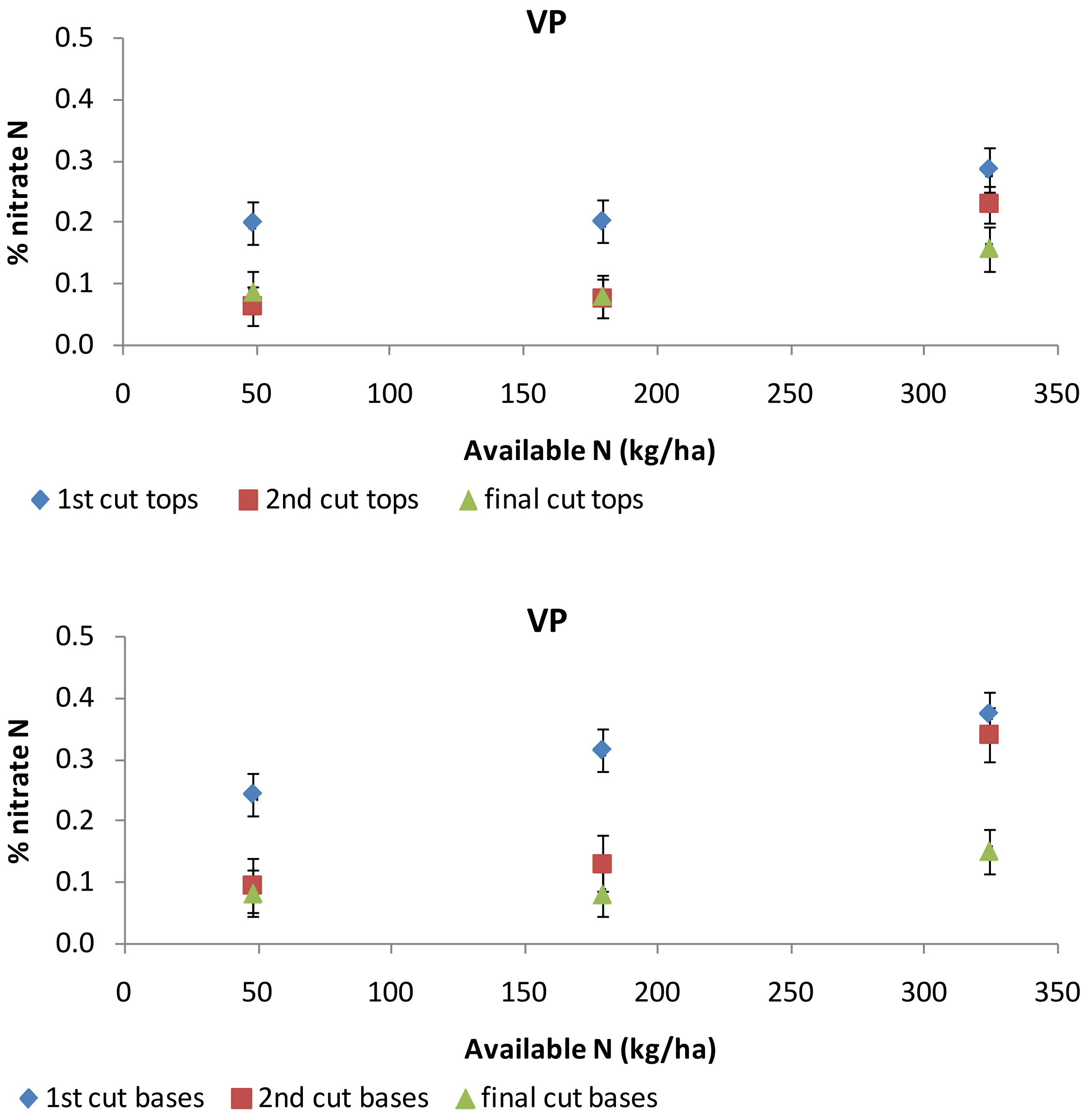


**Figure 31.** *Shoot nitrate N content from mint shoots harvested for topping and end of the first season cutting back of VP plots separated into tops representing marketable portion of the stem and bases representing residual shoot material cut back to ground level (error bars indicate standard error).*

In Years 1 and 2, maximum levels of % organic N in tops and bases were similar at both WHRI and VP, although the minimum % organic N levels were lower at WHRI than at VP (Table 15). In Year 1, a similar trend in % nitrate levels was also observed, with the maximum levels being similar at both sites but the minimum levels being lower at WHRI (Table 16). In Year 2 however, there was a much smaller range in % nitrate levels at VP than at WHRI. The minimum % nitrate levels in tops and bases were lower at WHRI than at VP, but the maximum values were higher (Table 16).

**Table 15.** Comparison of minimum and maximum % organic N in mint shoot tops and bases for a range of available N levels at WHRI and VP

| | | Tops | | Bases | |
|---|---|---|---|---|---|
| | | WHRI | VP | WHRI | VP |
| Year 1 | 1st Cut | 2.27 – 2.82 | 3.83 – 4.32 | – | 3.10 – 3.35 |
| | 2nd Cut | 2.32 – 4.32 | 3.05 – 3.93 | – | 1.46 – 2.02 |
| | 3rd Cut | 1.79 – 2.31 | 2.77 – 3.36 | 0.36 – 0.79 | 1.29 – 1.74 |
| Year 2 | 1st Cut | 1.89 – 4.03 | 3.65 – 4.18 | 0.70 – 2.23 | 1.96 – 2.49 |
| | 2nd Cut | 1.99 – 3.82 | 2.78 – 2.94 | 0.78 – 2.14 | 1.36 – 1.65 |
| | 3rd Cut | 1.83 – 3.47 | – | 0.61 – 1.49 | 1.11 – 1.61 |

**Table 16.** Comparison of minimum and maximum % nitrate N in mint shoot tops and bases for a range of available N levels at WHRI and VP

| | | Tops | | Bases | |
|---|---|---|---|---|---|
| | | WHRI | VP | WHRI | VP |
| Year 1 | 1st Cut | 0.00 – 0.05 | 0.20 – 0.29 | – | 0.24 – 0.37 |
| | 2nd Cut | 0.01 – 0.35 | 0.07 – 0.23 | – | 0.10 – 0.34 |
| | 3rd Cut | 0.00 – 0.03 | 0.08 – 0.16 | 0.00 – 0.20 | 0.08 – 0.15 |
| Year 2 | 1st Cut | 0.00 – 0.36 | 0.03 – 0.06 | 0.00 – 0.23 | 0.06 – 0.12 |
| | 2nd Cut | 0.01 – 0.68 | 0.01 – 0.01 | 0.00 – 0.08 | 0.01 – 0.02 |
| | 3rd Cut | 0.01 – 0.51 | – | 0.00 – 0.59 | 0.21 – 0.46 |

Most of the nitrogen in the shoot tops was in organic N, with only a small proportion as nitrate N (Table 17). Total N, organic and nitrate N were similar at WHRI and Valley Produce (Table 17). Nitrogen levels were highest in the shoots during the first year (in the second cut at WHRI and in the first cut at Valley Produce).

**Table 17.** Indication of mint shoot tops N content based on treatments producing maximum growth from each cutting.

| Shoot tops N content for plots producing maximum growth: | | | | |
|---|---|---|---|---|
| | | % Organic N | % $NO_3$-N | % Total N |
| **WHRI** | | | | |
| Year 1 | 1st Cut | 2.41 | 0.01 | 2.42 |
| | 2nd Cut | 4.03 | 0.26 | 4.29 |
| | 3rd Cut | 2.31 | 0.03 | 2.35 |
| Year 2 | 1st Cut | 3.48 | 0.08 | 3.56 |
| | 2nd Cut | 2.88 | 0.02 | 2.90 |
| | 3rd Cut | 2.82 | 0.07 | 2.89 |
| **VP** | | | | |
| Year 1 | 1st Cut | 3.83 | 0.20 | 4.03 |
| | 2nd Cut | 3.05 | 0.07 | 3.11 |
| | 3rd Cut | 2.77 | 0.09 | 2.85 |
| Year 2 | 1st Cut | 3.65 | 0.03 | 3.68 |
| | 2nd Cut | 2.94 | 0.01 | 2.95 |

*Nitrogen offtake*

Levels of N expected to be removed at harvest (i.e. within all plant material removed during harvesting) may be calculated in order to indicate appropriate rates of fertiliser required to balance this net uptake. This has been estimated from the experimental data by multiplying average dry weight yield by organic N content (since nitrate N content suggests luxury feeding which should be managed to a minimum); these data are summarised in Table 18. Since the yield data is expressed on a cropped area basis, these data could be adjusted to 75% of the given figures to account for unproductive area (wheelings / headland) which equates to rates of N offtake between 10 and 202 kg N per ha cropped area (i.e. 7.5 to 151.5 kg N per ha of total field area). In year 1, the second cut had the highest N offtake at WHRI and VP. In year 2, the first and second cuts had higher N offtakes than the third cut at WHRI. In years 1 and 2, the highest rates of available N produced highest calculated N offtake at WHRI, although level of available N at VP had no significant influence in year 1 (Table 18). The N offtakes for mint at optimum available N ranged from 15 kg N/ha in the first cut of Year 1 to 179 kg N/ha in the first cut of the second year (equivalent to 11.3 and 134.3 kg N /ha allowing for unproductive area).

**Table 18.** Calculated N offtake (kg/ha) in mint shoots harvested for topping (1st and 2nd cuts Year 1) and tops + bases (3rd cut Year 1 and all cuts Year 2) for a range of available N levels at WHRI and VP

| Available N (kg/ha) | WHRI | | | | VP | | |
|---|---|---|---|---|---|---|---|
| | 1st cut | 2nd cut | 3rd cut | Total | 1st cut | 2nd cut | 3rd cut |
| **Year 1** | | | | | | | |
| 29-48 | 11 | 10 | 13 | 34 | - | - | - |
| 49-65 | 15 | 34 | 15 | 64 | 16 | 36 | 45 |
| 69-83 | 16 | 51 | 21 | 88 | - | - | - |
| 102-129 | 21 | 55 | 28 | 97 | 11 | 41 | 49 |
| 136-182 | 18 | 47 | 29 | 94 | - | - | - |
| 229 | 27 | 65 | 43 | 135 | 12 | 50 | 54 |
| **Year 2** | | | | | | | |
| 4-6 | 63 | 37 | 26 | 126 | - | - | - |
| 32-65 | 93 | 92 | 63 | 248 | - | - | - |
| 78-118 | 113 | 124 | 84 | 321 | - | - | - |
| 131-172 | 156 | 165 | 105 | 426 | - | - | - |
| 246-297 | 179 | 178 | 107 | 464 | - | - | - |
| 336-446 | 202 | 193 | 109 | 504 | - | - | - |

*Estimation of critical N*

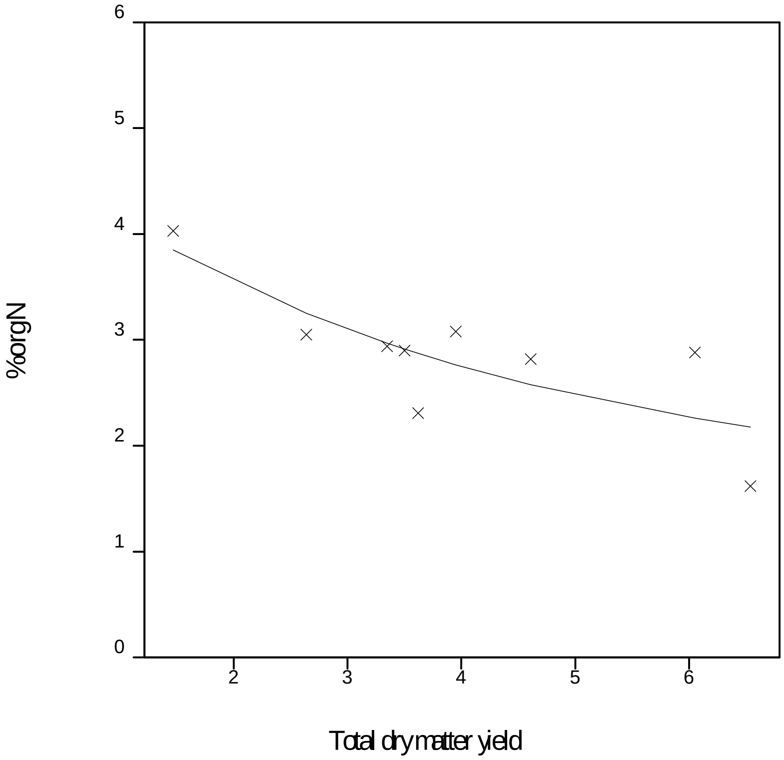


**Figure 32.** *Critical N curve for mint grown in trials at WHRI and VP in Years 1 and 2.*

In order to determine a general recommendation for mint N requirements, the data from the WHRI and VP trials have been collated to generate a critical N curve, in the same way as for coriander (Figure 32). Points on the curve are taken from each sample of each cutting in Years 1 and 2, with the % organic N shoot content plotted for the samples representing maximum yield on each occasion against the relevant dry weight yield figure. This curve may be used to estimate organic N content of a crop of dry weight within the range 0-7 t/ha which may be used to refine N offtake predictions based on local conditions and hence expected yield. Points below the critical N curve indicate a crop grown with insufficient available N which is sensible for this treatment.

*Calculation of N fertiliser recommendation*

Taking the data from the critical N curve and using the assumptions noted in Table 19 which are based on the trials at WHRI and VP with an N offtake of around 153 kg/ha, preliminary recommendations for mint N requirements per cut have been calculated (Table 20). These recommendations are for each of three cuttings in an established crop in the second year.

**Table 19.** Assumptions used for calculating preliminary fertiliser recommendations for mint based on mint crops at WHRI and VP in 2009 and 2010

| | | |
|---|---|---|
| **Potential Marketable Fresh wt Yield (t/ha)** | 25 | 3.13 t/ha DW Max Yield harvested.<br>(59% of crop grown) |
| **DM% Marketable** | 12.3 | Average DM% in marketable tops at opt N level. |
| **DW Harvest Index** | 0.59 | |
| **Calculated Total DM (t/ha)** | 5.3 | |
| **Calculated N Offtake** | 153 | Critical N% (organic N) = $a(1+be^{-0.26W})$<br>a = 1.567 and b = 3.344<br>w= total dry matter yield (t/ha) |
| **Max Rooting Depth (cm)** | 30 | |
| **Recovery Fertiliser %** | 60 | |
| **Mineralisation (kg/ha)** | 27.6 | 28th May for 39 days |

**Table 20.** Preliminary N fertiliser recommendations for each cutting of an established mint crop.

| **SNS Index*<br>(Mineral N (kg/ha) to 90cm)** | **0<br>(50)** | **1<br>(70)** | **2<br>(90)** | **3<br>(110)** | **4<br>(140)** | **5<br>(200)** | **6<br>(250)** |
|---|---|---|---|---|---|---|---|
| **Proposed rate of N (kg/ha)** | **180** | **170** | **160** | **150** | **130** | **100** | **70** |

*(*Note: SNS index in the Defra Fertiliser Manual are based on assessments of mineral N to 90 cm depth based on previous crop, soil type and over-winter rainfall. SNS index has to be estimated from measurements of mineral N to 30cm (rooting depth). To use SNS tables, the measurement to 30 cm should be multiplied by 3 to provide the relevant SNS index relevant to mint).*

The figures in the above Table assume that the base material from the shoots (and the associated nitrogen content) is removed from the field after cutting. If the bases remain in the field after cutting, the figures should be reduced by 30 kg/ha N to allow for the nitrogen content of the bases which becomes available to the next cutting. This figure represents around 50% of the total N content of the shoot base material. The precise figure requires further experimentation, with and without removal of shoot bases from plots.

### *Quality and shelf life responses of mint response to N*

Although plots were establishing in year one, bunches from the final, end of season cut at WHRI were evaluated for performance in shelf life. Bunch weight gradually declined as time in shelf life increased as might be expected, but there were no trends to indicate that this change in weight was influenced by available N during production (Figure 33).

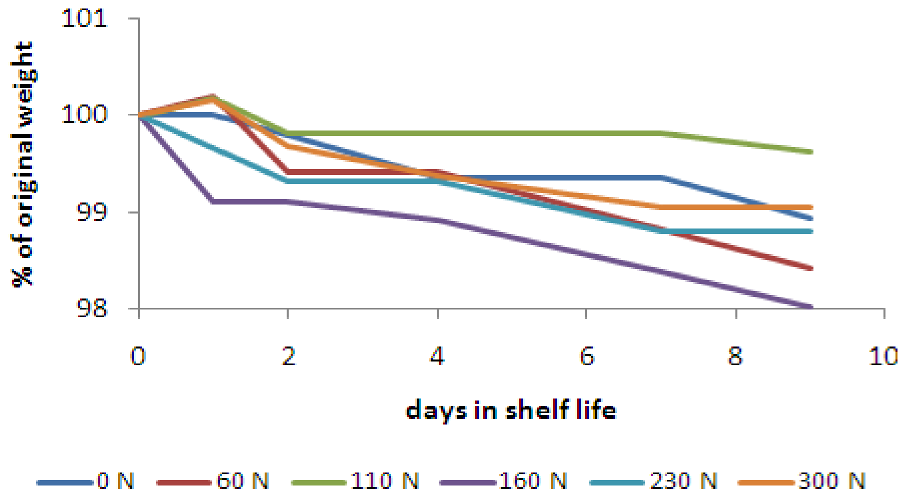


**Figure 33.** *Change in bunch weight with time for mint grown at a range of applied N levels and stored in shelf life in Year 1.*

Leaf browning/necrosis, possibly due to secondary infection, determined length of storage period with bunches assessed as being unsuitable for further use due to incidence of leaf browning within 9 days of storage (Figure 34). In Year 1, level of available N did not appear to influence incidence of leaf browning. The timing of the harvest for these bunches (5th October) may have influenced the incidence of infection since conditions in the field would be well suited to general fungal infection.

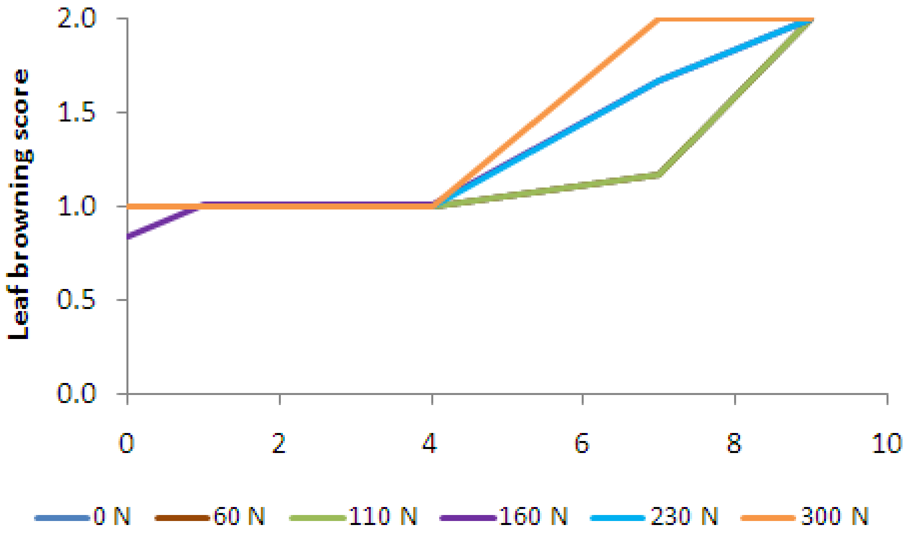


**Figure 34.** *Change in browning score with time for mint grown at a range of applied N levels and stored in shelf life in Year 1.*

In Year 1 leaf greenness (as measured by a SPAD meter) was not influenced by level of available N at the start of shelf life and there was little change in this parameter during the storage period assessed. Bunches became less turgid (i.e. wilted) during storage, increasing from a score of 0 to 1 over the period assessed but were not considered to have wilted fully within this period. Leaf yellowing score, to indicate incidence of leaves that had become yellow rather than overall bunch leaf colour as determined by SPAD, increased slightly with time in shelf life but was also not influenced by level of available N. Hence there is little indication from this preliminary assessment that level of available N influenced bunch shelf life of mint in year 1 when plots were establishing.

In Year 2, there was a highly significant effect of available N on leaf greenness measured with SPAD meter (Figs. 35 and 37). Leaf greenness was higher in the second cutting than in the first or third cuttings, particularly at N availability levels above 118 kg/ha. Leaf greenness increased with increasing N availability up to 78 and 171 kg/ha for the first and second cuttings respectively. There were no further increases in leaf greenness at higher levels of available N. In the third cutting, leaves were significantly greener from plots with 283 kg/ha available N than from plots with 122 kg/ha available N. However, there were no intermediate levels of available N between these values so it is possible that the same level of greenness would have been achieved at a level of available N less than 283 kg/ha.

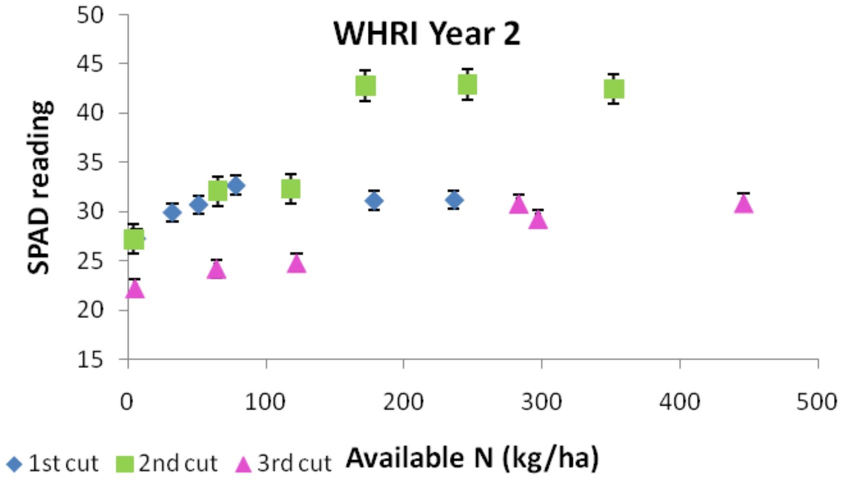


**Figure 35.** *Effect of available N on leaf greenness of bunches of mint at the start of shelf life.*

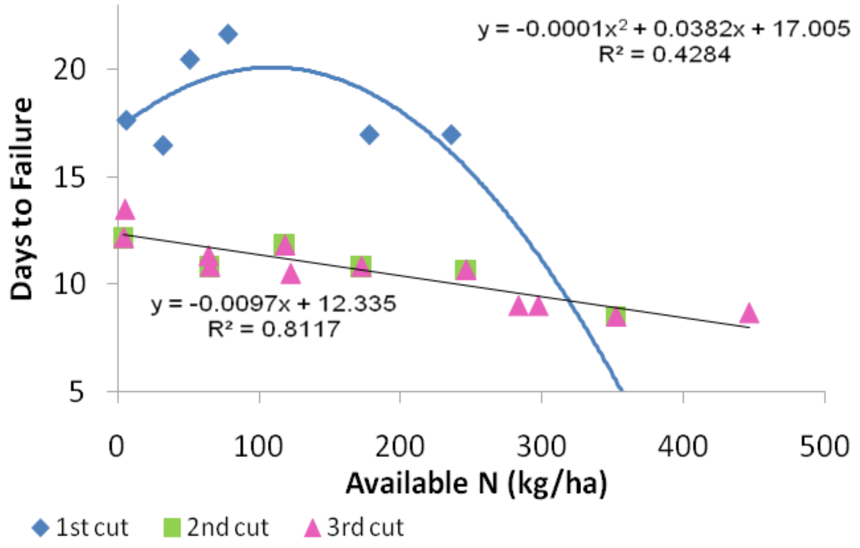
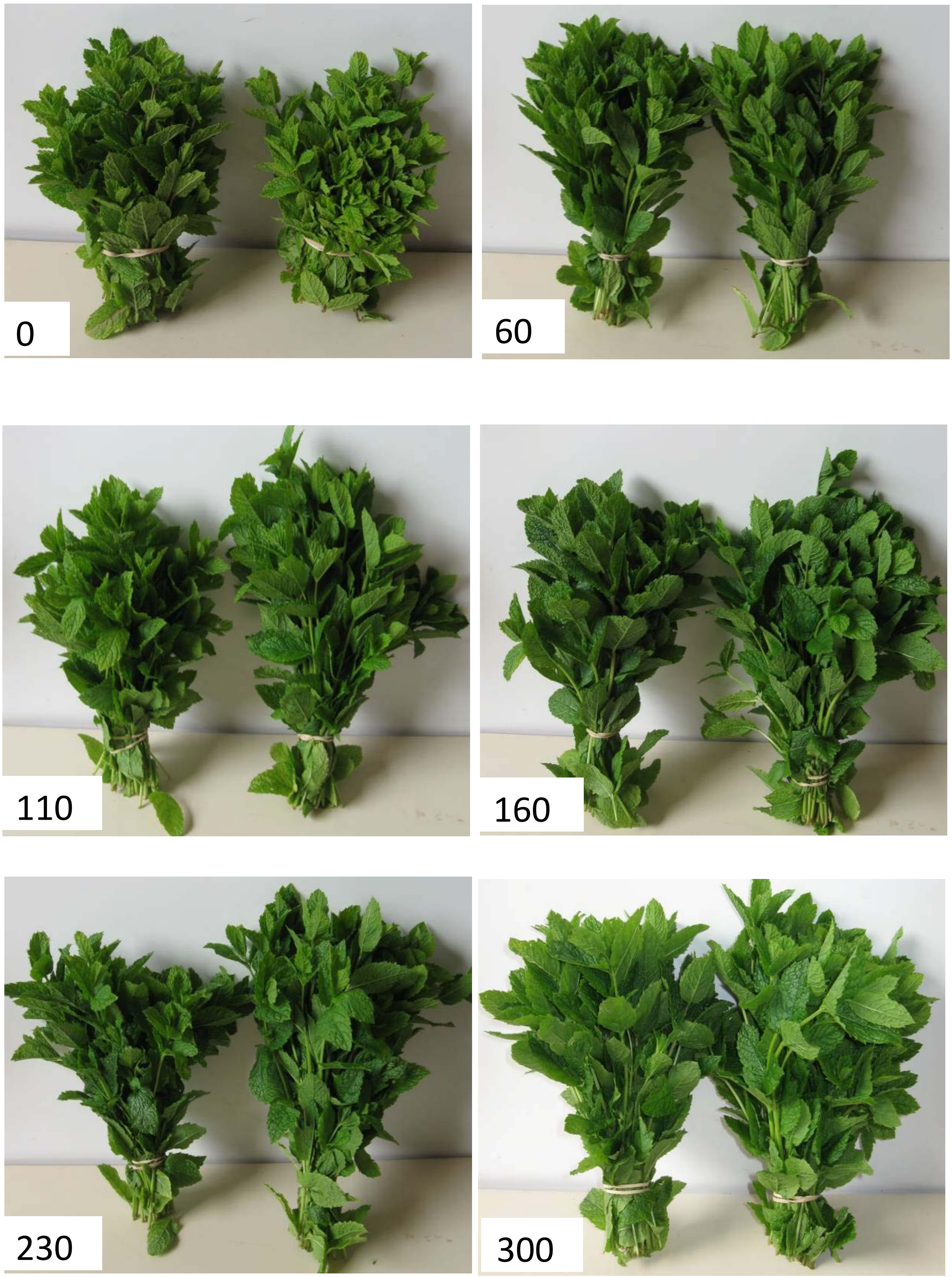


**Figure 36.** *Effect of available nitrogen on days to failure in shelf life (mainly due to leaf necrosis and some yellowing).*

As in Year 1, there was only a small change in the SPAD meter readings during shelf life during Year 2. Although leaf yellowing resulted in shelf life failure of some samples, the main cause of shelf life failure in Year 2 was leaf browning necrosis. None of the samples failed due to wilting; weight loss during 14 days of shelf life was about 3% in all the treatments. Samples from the first cut had a longer shelf life than those from the second and third cuts (Fig. 36). The effect of available N on shelf life also differed between the first cut and the second and third cuts. In the first cut, samples from plots with available N of 51-78 kg/ha had a significantly longer shelf life than samples from plots with lower or higher levels of available N. However, in the later cuts, increasing levels of available N reduced shelf life, with a difference of 5 days between samples from the lowest and highest levels (Fig. 36).



**WHRI Mint bunches at**

**Figure 37.** *Comparison of bunches of mint at the start of shelf life from the range of applied N treatments (third cutting in Year 2).*

## Discussion

*Coriander trials:*

Response of coriander to N treatment was clear for the plots at WHRI. For the earliest drilling date, plots responded to increasing N by increasing yield up to the higher treatment levels (255 – 325 kg/ha available N). For later drillings, where lower yield and hence N offtake was lower, and when release of N via soil mineralisation might be expected to make a greater contribution to the N demands of the crop, lower rates of applied N resulted in the highest yields. Results of trials carried out on the commercial site were less clear cut. For the first drilling date, it was clear that the commercial site had substantially higher background N (equivalent to an extra 190 kg/ha N to 30cm depth of soil), and whilst initial soil mineral N content for the second drilling date at VP was more comparable with that at WHRI, there may have been differences in the contribution from soil mineralisation between the two sites. Positional effect is also likely to have impacted on results from VP trials as noted previously but the sequential application of rates was necessary given the logistics of this commercial operation. The VP data does however provide a useful commercial benchmark for the WHRI data and the critical N curve derived from it.

The critical N curve for coriander has been produced using 9 sets of sample data across the 6 rates of N tested. The curve offers a good fit for the WHRI experimental data. Furthermore when data from the commercial trials are also plotted on this graph, they fit into predictable positions relative to the curve (e.g. plots grown with 0 N and with low initial soil mineral N falling below the curve suggesting lower than ideal N content in shoot tissue). These data have been utilized in the framework for N recommendations in the current revision of RB209 for the provision of a new recommendation table for coriander. Whilst based on high fresh weight yields, the recommendations do ensure that lower yielding crops will not suffer from lack of N supply due to falling below required soil N concentration (which is likely to exceed the calculated N requirement).

Beyond establishing data which may be used to support future decisions on N fertiliser rates, the wider range of mineral elements also analysed as part of the standard tissue analyses undertaken have been compiled into the summary table below (Table 21). These data are designed to provide an overview of shoot mineral content for crops growing ‘well’ (i.e. they focus on those N treatments which were producing the highest yield for each sample date), and are broken down into interim samples (which provide an opportunity to correct for nutrient imbalances during production) and also the final sample which provides information about total crop offtake. Data available from the scientific literature have also been summarised to supplement this information. % P levels in shoots harvested from WHRI and VP trials are generally lower than in the data from the two literature sources. % K levels from WHRI and VP trials are high compared with the data from samples in Australia (Hooper & Dennis, 2002), whilst the data from Broadley *et al.*, (2004) is at the higher end of the range of values for %K in shoots at final harvest from the two experimental sites. % Ca data in the literature is lower than or at the lower end of the range found for the experimental data produced here. The data from the current trials are comparable for % Mg data produced by Broadley *et al*., (2004) but are low compared with the Hooper and Dennis (2001) data for Australian production. Comparison of micronutrient data is likely to be less reliable since plants grown in the trials were treated regularly with Cu fungicides and also with a micronutrient foliar spray and hence it is difficult to determine if any of the elements analysed has been taken up into shoot tissue, or remains as a coating on the leaf surface (which may not have been adequately removed when washing shoots prior to oven drying). For both Fe and Cu, the range of values from the Australian work (Hooper and Dennis, 2001) are wide, and hence overlap with data generated from the trials covered by this report.

**Table 21.** *Indication of coriander leaf mineral element content based on treatments producing maximum growth from each trial drilled compared with data available from the literature*

| **Shoot mineral content for plots producing maximum growth:** | | | | | | |
|---|---|---|---|---|---|---|
| **sample / drilling** | **% P** | **% K** | **% Mg** | **% Ca** | **µg/g Fe*** | **µg/g Cu*** |
| **WHRI** | | | | | | |
| **interim 1 sample (at 4-5 true leaves)** | | | | | | |
| **drilled 21/05/09** | 0.29-0.43 | 3.58-4.53 | 0.23-0.37 | 1.09-1.31 | - | 11.4-14.5 |
| **drilled 23/07/09** | 0.34-0.40 | 4.99-5.78 | 0.28-0.33 | 1.14-1.26 | 499-1159 | 13.4-35.7 |
| **drilled 11/08/09** | 0.30-0.39 | 5.14-6.26 | 0.29-0.34 | 1.00-1.25 | 272-642 | 6.3-9.9 |
| **interim 2 sample (at 7-9 true leaves)** | | | | | | |
| **drilled 21/05/09** | 0.22-0.38 | 4.16-5.68 | 0.25-0.36 | 0.90-1.37 | - | 17.9-38.7 |
| **drilled 23/07/09** | 0.37-0.45 | 4.66-5.38 | 0.29-0.31 | 0.94-1.09 | 1629-3724 | 9.7-13.5 |
| **drilled 11/08/09** | 0.34-0.41 | 4.34-4.93 | 0.33-0.40 | 1.02-1.11 | 1114-1546 | 8.0-10.7 |
| **Final harvest sample** | | | | | | |
| **drilled 21/05/09** | 0.36-0.45 | 5.77-6.71 | 0.28-0.41 | 1.12-1.35 | - | 12.9-34.4 |
| **drilled 23/07/09** | 0.33-0.40 | 6.61-7.39 | 0.28-0.31 | 1.21-1.35 | 215-320 | 22.6-31.6 |
| **drilled 11/08/09** | 0.33-0.43 | 6.51-7.21 | 0.27-0.34 | 1.27-1.39 | 266-466 | 17.2-25.9 |
| **VP** | | | | | | |
| **interim sample (at 7-9 true leaves)** | | | | | | |
| **drilled 17/06/09** | 0.50-0.79 | 5.36-7.29 | 0.25-0.32 | 1.53-1.77 | 454-1564 | 9.5-34.4 |
| **drilled 11/08/09** | 0.26 | 4.92-5.01 | 0.21-0.22 | 1.60-1.63 | 170-181 | 36.5-39.0 |
| **Final harvest sample** | | | | | | |
| **drilled 17/06/09** | 0.68-0.79 | 6.20-7.29 | 0.30-0.32 | 1.67-1.77 | 621-1469 | 9.5-34.4 |
| **drilled 11/08/09** | 0.38-0.40 | 5.88-6.01 | 0.24-0.26 | 1.90-1.97 | 243-247 | 30.4-34.6 |
| **Data from the literature** | | | | | | |
| **Hooper & Dennis (2001):** | | | | | | |
| **Range from 2 yrs** | 0.27-0.72 | 2.6-6.7 | 0.18-0.45 | 0.68-1.8 | 72-2094 | 4.0-74.0 |
| **Average** | 0.46 | 3.95 | 0.36 | 1.15 | 222 | 30.9 |
| **Broadley et al** | 0.57 | 7.21 | 0.29 | 0.64 | | |
| * note micronutrients may be affected by timing of fungicide application (especially Cu) and foliar micronutrients applications) | | | | | | |

Using figures for anticipated yield in a specific cropping system, it would be possible to use the summary mineral analysis data to calculate anticipated offtake of nutrient at harvest and balance this against anticipated availability (i.e. from knowledge of the field to be cropped).

This was done for organic N figures in the results section above, across the range of available N levels tested (Table 8). Applying comparable calculations for the trials being reported here i.e. taking final yield from the final sample of the WHRI trials at the rate of N producing the highest yield, offtake for P, K, Mg and Ca have been estimated on a cropped area basis (Table 22). As stated earlier, these figures would need to be adjusted to total field area by accounting for unproductive area such as wheelings and headlands. Since these experiments have focused on suitable N levels, these calculated offtake figures for the wider range of elements analysed will be less accurate as an indicator of the requirements for a crop growing optimally, but given the lack of alternative UK based data, it does at least provide a starting point to understanding the wider needs of the crop. As noted previously, yield from the May drilling is considered to be high compared with commercial estimates. It should also be noted that P offtake is a poor indicator of requirement since concentration of available P is a main factor to consider when determining suitable P fertiliser rates.

**Table 22.** *Calculated offtake (kg/ha of cropped area) by coriander for a range of available N levels and drilling dates at WHRI*

| | **Calculated mineral offtake (kg/ha)** | | | |
|---|---|---|---|---|
| **Drilling date** | **P** | **K** | **Mg** | **Ca** |
| **21/05/2009** | **14.0** | **233.6** | **12.9** | **48.0** |
| **23/07/2009** | **4.5** | **84.8** | **3.6** | **15.3** |
| **11/08/2009** | **6.6** | **117.5** | **5.2** | **22.5** |

Applying extra K to plots did not influence yield at harvest stage and had no significant influence on shelf life of coriander. Level of available N had the greatest impact on coriander shelf life with higher N generally resulting in poorer shelf life. Unfortunately where N rate had a statistically significant impact on shelf life, bunch quality at harvest was also negatively impacted such that the produce is likely to be marketable. It therefore seems unlikely that improvements in product shelf-life can be generated by reducing rate of N. Informal, unreplicated observations suggested some shelf life benefit from applying NaCl as a top dressing to improve product shelf life, which was also reported for protected coriander grown hydroponically (Flowers and Bashtanova, 2008), but these results would require more robust experimentation to be verified. It seems possible however that the rates of NaCl required to make an impact may result in a detrimental impact on soil quality in the longer term and hence may not be of practical benefit for soil grown crops.

*Mint trials*

For year 1 data, there were different responses to available N between the two trial sites. For WHRI plots, increasing N applied up to 229 kg/ha, resulted in higher yield whereas at VP the only response was for a decrease in ‘bases’ harvested at higher rates of N. Comparison of initial nutrient status suggests that WHRI plots had just under twice the mineral N contents of VP plots in the 0-30 cm layer of soil, but these differences seem too small to explain the variation between the two alone. However given the longer production period for mint crops, potential contribution to available N from soil mineralisation is greater (in comparison with coriander) and has potential to make a greater contribution to N offtake during the season.

In Year 2 at WHRI, there was a clear response of mint yield to available N. The optimum available N for the yield of total shoot weight and plant bases was 118-122 kg/ha. Although these weights did not increase significantly at higher levels of available N, the yield of plant tops continued to increase slightly up to 178-283 kg/ha, although the difference in yield with that achieved at available N of 118-122 kg/ha was very small and only statistically significant for the second and third cuts.

**Table 23.** *Indication of mint shoot mineral element content for 2009 based on treatments producing maximum yield from harvest*

| Shoot mineral content for plots producing maximum growth | | | | | | |
|---|---|---|---|---|---|---|
| **Sample** | **% P** | **% K** | **% Mg** | **% Ca** | **µg/g Fe*** | **µg/g Cu*** |
| **WHRI** | | | | | | |
| **Shoots removed for topping** | | | | | | |
| **07/07/2009** | **0.42-0.49** | **2.62-3.02** | **0.41-0.42** | **1.42-1.63** | **179-241** | **8.9-10.7** |
| **06/08/2009** | **0.46-0.52** | **3.27-3.62** | **0.42-0.48** | **1.37-1.64** | **212-373** | **11.1-15.4** |
| **07/10/2009** | **0.29-0.34** | **2.87-3.14** | **0.26-0.35** | **1.10-1.32** | **102-137** | **8.0-9.2** |
| **Stem bases cut back after topping (3rd cut only)** | | | | | | |
| **07/10/2009** | **0.22-0.33** | **1.42-2.13** | **0.18-0.35** | **0.52-1.22** | **96-371** | **5.7-7.5** |
| **VP** | | | | | | |
| **Shoots removed for topping** | | | | | | |
| **30/06/2009** | **0.34-0.45** | **2.85-3.30** | **0.45-0.65** | **1.43-2.02** | **134-194** | **8.8-10.8** |
| **23/07/2009** | **0.43-0.52** | **2.52-3.27** | **0.49-0.52** | **1.47-1.74** | **111-144** | **9.2-11.2** |
| **22/09/2009** | **0.26-0.33** | **2.69-3.27** | **0.41-0.46** | **1.06-1.41** | **72-94** | **8.0-10.3** |
| **Stem bases cut back after topping** | | | | | | |
| **30/06/2009** | **0.39-0.41** | **2.95-3.39** | **0.48-0.54** | **1.39-1.49** | **287-354** | **11.1-12.0** |
| **23/07/2009** | **0.39-0.46** | **3.33-3.47** | **0.26-0.37** | **0.69-1.30** | **147-515** | **10.1-11.1** |
| **22/09/2009** | **0.20-0.23** | **2.22-3.13** | **0.31-0.38** | **0.77-1.04** | **80-95** | **5.9-7.6** |

There were also clear effects of available N on leaf greenness in Year 2, with samples grown on plots with available N of 78-172 kg/ha having greener leaves at harvest than those grown on lower levels of available N. However, leaf greenness did not continue to increase at even higher levels of available N.

In Year 1, mint shelf life was assessed on the final bunches harvested from WHRI in October 2009 and none of the data from this assessment suggested any response to N availability within the range tested. Shelf life of mint was however shorter than expected at up to 9 days and was finished as a result of leaf browning and necrosis. However, in Year 2, there were clear effect of available N and cutting date on mint shelf life, with high levels of available N reducing shelf life, mainly due to browning and necrosis.

**Table 24.** Indication of mint shoot mineral element content for 2010 based on treatments producing maximum yield from harvest.

| Shoot mineral content for plots producing maximum growth: | | | | | | |
|---|---|---|---|---|---|---|
| **Sample** | **% P** | **% K** | **% Mg** | **% Ca** | **µg/g Fe*** | **µg/g Cu*** |
| **WHRI** | | | | | | |
| **Shoots removed for topping** | | | | | | |
| 12/05/2010 | 0.45-0.47 | 4.57-4.67 | 0.34-0.44 | 1.07-1.16 | 118-159 | 7.6-8.4 |
| 06/07/2010 | 0.34-0.37 | 3.34-3.68 | 0.46-0.59 | 1.26-1.48 | 79-84 | 9.1-10.1 |
| 08/09/2010 | 0.36-0.43 | 3.89-4.38 | 0.30-0.43 | 1.01-1.27 | 80-90 | 9.4-10.9 |
| **Stem bases cut back after topping** | | | | | | |
| 12/05/2010 | 0.24-0.33 | 3.08-3.95 | 0.13-0.17 | 0.50-0.70 | 52-78 | 4.3-6.1 |
| 06/07/2010 | 0.35-0.36 | 3.36-3.81 | 0.18-0.26 | 0.70-0.90 | 38-54 | 8.1-8.6 |
| 08/09/2010 | 0.33-0.40 | 3.26-3.70 | 0.15-0.16 | 0.53-0.61 | 34-55 | 8.1-9.4 |
| **VP** | | | | | | |
| **Shoots removed for topping** | | | | | | |
| 11/05/2010 | 0.46-0.53 | 4.57-5.16 | 0.44-0.48 | 1.19-1.42 | 102-117 | 8.8-10.5 |
| 07/07/2010 | 0.37-0.38 | 3.11-3.61 | 0.43-0.45 | 1.18-1.41 | 86-88 | 9.6-9.9 |
| 07/09/2010 | Tops already removed by VP | | | | | |
| **Stem bases cut back after topping** | | | | | | |
| 11/05/2010 | 0.30-0.35 | 3.95-4.29 | 0.26-0.30 | 0.94-0.96 | 147-173 | 7.1-8.3 |
| 07/07/2010 | 0.28-0.31 | 3.30-4.20 | 0.23-0.40 | 0.78-1.29 | 58-97 | 6.4-7.5 |
| 07/09/2010 | 0.34-0.38 | 3.87-4.07 | 0.22-0.24 | 0.61-0.74 | 50-102 | 6.2-8.5 |

Levels of mineral elements, other than N, in mint treatments grown at optimum available N are summarized in Tables 23 and 24. The levels of P, K, Mg, Ca, Fe and Cu in mint shoots from the three cuttings in 2009 and 2010 at WHRI and VP are similar. The offtake of P, K, Mg and Ca in mint crops at WHRI in 2009 and 2010 is summarized in Table 25. Compared with coriander (Table 22), mint had a relatively higher P offtake.

**Table 25.** *Calculated offtake of mineral elements (kg/ha of cropped area) by mint for maximum yields from harvests of individual cuts at WHRI.*

| | Calculated mineral offtake (kg/ha) | | | |
|---|---|---|---|---|
| | P | K | Mg | Ca |
| **Year 1** | | | | |
| 1st Cut (tops) | 2.8 | 17.2 | 2.5 | 9.3 |
| 2nd Cut (tops) | 6.4 | 45.1 | 5.9 | 19.7 |
| 3rd Cut (tops + bases) | 10.7 | 86.5 | 11.0 | 37.6 |
| **Year 2** | | | | |
| 1st Cut (tops + bases) | 24.1 | 262.3 | 17.4 | 55.3 |
| 2nd Cut (tops + bases) | 21.5 | 214.6 | 22.5 | 65.6 |
| 3rd Cut (tops + bases) | 17.5 | 175.5 | 11.9 | 39.4 |

## Conclusions

- Clear yield responses of coriander and mint to applied and available N were observed in trials at WHRI and the data from these trials have been used to generate preliminary N fertiliser recommendations.

- Applying extra fertiliser K did not influence shelf life of coriander grown with either low (60 kg/ha), standard (160 kg/ha) or high (230 kg/ha) rates of fertiliser N.

- Leaf greenness of coriander and mint were improved by N applications, but there were no further increases in greenness at levels of available N above 131-172 kg/ha.

- Wilting was the main factor determining the shelf life of coriander; samples grown without N application wilted the slowest but these had poor leaf colour quality. Where N was applied at 60 kg/ha or more, differences in wilting between N rates were small or not significant.

- Browning/ necrosis was the main factor determining the shelf life of mint. In the first cut of the second season, samples grown on plots with 51-78 kg/ha available N had a longer shelf life than samples grown on plots with lower or higher levels of available N; in the second and third cuts, shelf life decreased with increasing availability of N.

## Technology transfer

Noble R, Wilson D. (2011). When too much nitrogen is luxury for herbs. *HDC News* March 2011.

Presentations delivered to British Herb Growers Association technical meeting at STC, 03rd March 2010 on coriander results and on 16th March 2011 on mint results. Featured in *Field Vegetables Review* 2010, p3 and 2011.

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## Appendix 1 Leaf tissue analysis data

Data has been collated into minimum and maximum levels detected in samples taken from the treatment producing the greatest yield on each occasion. The rate of N producing this yield is also indicated in each table. Samples of coriander were taken as the crop developed and at final harvest and hence the data also indicate how nutrient status may change as the crop progresses. As the trials examined response to N, the data for other nutrient elements cannot be expected to have been optimised but they do at least provide some guidance data for crops considered to be growing well.

### Coriander trials – Table A1

| | % organic N | % min N | % total N | %C | %P | %K | %Mg | %Ca | %Na |
|---|---|---|---|---|---|---|---|---|---|
| **WHRI:** | | | | | | | | | |
| **Drilled 21/05/09 - interim sample 1** | | | | | | | | | |
| **300 N Max** | 5.00 | 0.20 | 5.16 | 41.97 | 0.43 | 4.53 | 0.30 | 1.25 | 0.16 |
| **300 N Min** | 4.54 | 0.16 | 4.73 | 39.14 | 0.29 | 3.58 | 0.24 | 0.93 | 0.12 |
| **Drilled 21/05/09 - interim sample 2** | | | | | | | | | |
| **300 N Max** | 3.95 | 0.86 | 4.77 | 35.60 | 0.38 | 5.68 | 0.36 | 1.37 | 0.28 |
| **300 N Min** | 3.30 | 0.74 | 4.17 | 30.59 | 0.22 | 4.16 | 0.25 | 0.90 | 0.16 |
| **Drilled 21/05/09 - final sample** | | | | | | | | | |
| **230 N Max** | 3.74 | 1.06 | 4.72 | 36.01 | 0.45 | 6.89 | 0.41 | 1.35 | 0.40 |
| **230 N Min** | 2.71 | 0.58 | 3.37 | 28.70 | 0.32 | 5.54 | 0.28 | 1.12 | 0.25 |
| **Drilled 23/07/09 - interim sample 1** | | | | | | | | | |
| **160 N Max** | 5.13 | 0.76 | 5.72 | 41.96 | 0.40 | 5.78 | 0.33 | 1.26 | 0.26 |
| **160 N Min** | 4.82 | 0.50 | 5.51 | 39.75 | 0.34 | 4.99 | 0.28 | 1.14 | 0.21 |
| **Drilled 23/07/09 - interim sample 2** | | | | | | | | | |
| **110 N Max** | 4.23 | 0.47 | 4.70 | 40.12 | 0.44 | 5.38 | 0.31 | 1.09 | 0.06 |
| **110 N Min** | 3.95 | 0.43 | 4.38 | 36.08 | 0.37 | 4.66 | 0.29 | 0.94 | 0.02 |
| **Drilled 23/07/09 - final sample** | | | | | | | | | |
| **110 N Max** | 4.48 | 0.98 | 5.32 | 40.07 | 0.40 | 7.39 | 0.31 | 1.35 | 0.17 |
| **110 N Min** | 4.10 | 0.78 | 4.89 | 39.13 | 0.33 | 6.61 | 0.28 | 1.21 | 0.14 |
| **Drilled 11/08/09 - interim sample 1** | | | | | | | | | |
| **60 N Max** | 4.75 | 0.52 | 5.27 | 42.01 | 0.39 | 6.26 | 0.34 | 1.25 | 0.19 |
| **60 N Min** | 3.96 | 0.31 | 4.27 | 40.99 | 0.30 | 5.14 | 0.29 | 1.00 | 0.13 |
| **Drilled 11/08/09 - interim sample 2** | | | | | | | | | |
| **60 N Max** | 4.96 | 0.44 | 5.38 | 42.96 | 0.41 | 4.93 | 0.40 | 1.11 | 0.20 |
| **60 N Min** | 4.39 | 0.28 | 4.76 | 40.04 | 0.34 | 4.34 | 0.33 | 1.02 | 0.16 |
| **Drilled 11/08/09 - final sample** | | | | | | | | | |
| **60 N Max** | 4.14 | 0.74 | 4.88 | 40.39 | 0.42 | 7.28 | 0.34 | 1.43 | 0.38 |
| **60 N Min** | 3.05 | 0.08 | 3.13 | 38.98 | 0.33 | 6.51 | 0.26 | 1.26 | 0.24 |
| **VP:** | | | | | | | | | |
| **Drilled 17/06/09 - final sample** | | | | | | | | | |
| **380 N Max** | 4.48 | 1.07 | 5.55 | 37.29 | 0.79 | 7.29 | 0.32 | 1.77 | 0.05 |
| **380 N Min** | 3.97 | 0.94 | 4.91 | 35.33 | 0.68 | 6.20 | 0.30 | 1.67 | 0.05 |
| **Drilled 11/08/09 - final sample** | | | | | | | | | |
| **380 N Max** | 4.62 | 0.71 | 5.34 | 40.78 | 0.40 | 6.01 | 0.26 | 1.97 | 0.12 |
| **380 N Min** | 4.32 | 0.57 | 4.89 | 37.93 | 0.38 | 5.88 | 0.24 | 1.90 | 0.11 |

## Coriander trials – Table A2:

| | %S | µg/g B | µg/g Cu | µg/g Fe | µg/g Mn | µg/g Zn |
|---|---|---|---|---|---|---|
| **WHRI:** | | | | | | |
| **Drilled 21/05/09 - interim sample 1** | | | | | | |
| **300 N Max** | 0.37 | 25.19 | 12.46 | 2806.50 | 97.74 | 23.74 |
| **300 N Min** | 0.27 | 19.47 | 10.76 | 1542.89 | 70.14 | 17.92 |
| **Drilled 21/05/09 - interim sample 2** | | | | | | |
| **300 N Max** | 0.17 | 20.21 | 38.70 | 4093.91 | 115.22 | 26.65 |
| **300 N Min** | 0.03 | 13.85 | 17.86 | 3121.39 | 101.49 | 21.33 |
| **Drilled 21/05/09 - final sample** | | | | | | |
| **230 N Max** | 0.32 | 24.85 | 21.53 | 2529.14 | 86.86 | 29.69 |
| **230 N Min** | 0.26 | 21.68 | 11.92 | 1066.11 | 61.90 | 24.90 |
| **Drilled 23/07/09 - interim sample 1** | | | | | | |
| **160 N Max** | 0.37 | 24.45 | 35.68 | 1159.12 | 63.77 | 31.83 |
| **160 N Min** | 0.32 | 22.33 | 13.36 | 498.98 | 47.23 | 25.05 |
| **Drilled 23/07/09 - interim sample 2** | | | | | | |
| **110 N Max** | 0.31 | 21.23 | 13.48 | 3724.28 | 104.79 | 25.22 |
| **110 N Min** | 0.27 | 15.95 | 9.73 | 1629.07 | 74.51 | 23.28 |
| **Drilled 23/07/09 - final sample** | | | | | | |
| **110 N Max** | 0.35 | 25.35 | 31.63 | 319.75 | 49.82 | 33.89 |
| **110 N Min** | 0.33 | 24.33 | 22.64 | 214.71 | 43.81 | 26.33 |
| **Drilled 11/08/09 - interim sample 1** | | | | | | |
| **60 N Max** | 0.38 | 25.81 | 9.86 | 642.64 | 49.56 | 23.45 |
| **60 N Min** | 0.30 | 21.97 | 6.34 | 272.02 | 39.92 | 17.78 |
| **Drilled 11/08/09 - interim sample 2** | | | | | | |
| **60 N Max** | 0.38 | 37.77 | 10.71 | 1546.23 | 63.24 | 27.22 |
| **60 N Min** | 0.34 | 34.64 | 7.96 | 1113.82 | 54.55 | 22.80 |
| **Drilled 11/08/09 - final sample** | | | | | | |
| **60 N Max** | 0.38 | 29.61 | 25.86 | 496.27 | 48.88 | 25.66 |
| **60 N Min** | 0.28 | 25.17 | 16.69 | 237.67 | 38.16 | 20.87 |
| **VP:** | | | | | | |
| **Drilled 17/06/09 - final sample** | | | | | | |
| **380 N Max** | 0.32 | 25.30 | 34.44 | 1469.21 | 221.67 | 46.01 |
| **380 N Min** | 0.31 | 24.28 | 9.51 | 620.54 | 105.16 | 45.36 |
| **Drilled 11/08/09 - final sample** | | | | | | |
| **380 N Max** | 0.42 | 27.36 | 34.46 | 247.30 | 201.29 | 45.51 |
| **380 N Min** | 0.41 | 26.63 | 30.04 | 242.53 | 192.97 | 42.76 |

## Mint trials Year 1 – Table A3:

| | % organic N | % min N | % total N | %C | %P | %K | %Mg | %Ca | %Na |
|---|---|---|---|---|---|---|---|---|---|
| **WHRI - shoots removed for topping:** | | | | | | | | | |
| **07/07/2009 - first cut** | | | | | | | | | |
| **300 N Max** | 3.12 | 0.05 | 3.16 | 44.36 | 0.49 | 3.02 | 0.42 | 1.63 | 0.11 |
| **300 N Min** | 2.66 | 0.02 | 2.68 | 43.70 | 0.42 | 2.62 | 0.41 | 1.42 | 0.10 |
| **06/08/2009 - second cut** | | | | | | | | | |
| **300 N Max** | 4.68 | 0.38 | 5.05 | 44.58 | 0.52 | 3.62 | 0.48 | 1.64 | 0.05 |
| **300 N Min** | 3.85 | 0.32 | 4.17 | 44.24 | 0.46 | 3.27 | 0.42 | 1.37 | 0.04 |
| **07/10/2009 - final cut** | | | | | | | | | |
| **300 N Max** | 2.57 | 0.05 | 2.62 | 45.51 | 0.34 | 3.14 | 0.35 | 1.32 | 0.17 |
| **300 N Min** | 2.02 | 0.02 | 2.04 | 45.08 | 0.29 | 2.87 | 0.26 | 1.10 | 0.13 |
| **WHRI - Stem bases cut back after topping (final cut only in year 1 at WHRI):** | | | | | | | | | |
| **07/10/2009 - final cut** | | | | | | | | | |
| **300 N Max** | 1.32 | 0.04 | 1.35 | 44.49 | 0.33 | 2.13 | 0.35 | 1.22 | 0.27 |
| **300 N Min** | 0.35 | 0.00 | 0.35 | 43.96 | 0.22 | 1.42 | 0.18 | 0.52 | 0.16 |
| **VP - shoots removed for topping:** | | | | | | | | | |
| **30/06/2009 - first cut** | | | | | | | | | |
| **131 N Max** | 4.48 | 0.28 | 4.76 | 44.26 | 0.45 | 3.30 | 0.65 | 2.02 | 0.06 |
| **131 Min** | 3.33 | 0.15 | 3.48 | 42.46 | 0.34 | 2.85 | 0.45 | 1.43 | 0.05 |
| **23/07/2009 - second cut** | | | | | | | | | |
| **131 N Max** | 3.54 | 0.16 | 3.70 | 44.87 | 0.52 | 3.27 | 0.52 | 1.74 | 0.04 |
| **131 Min** | 3.04 | 0.04 | 3.08 | 43.06 | 0.43 | 2.52 | 0.49 | 1.47 | 0.03 |
| **22/09/2009 - final cut** | | | | | | | | | |
| **131 N Max** | 3.22 | 0.11 | 3.31 | 45.01 | 0.33 | 3.27 | 0.46 | 1.41 | 0.04 |
| **131 Min** | 2.68 | 0.04 | 2.79 | 43.96 | 0.26 | 2.69 | 0.41 | 1.06 | 0.03 |
| **VP - Stem bases cut back after topping:** | | | | | | | | | |
| **30/06/2009 - first cut** | | | | | | | | | |
| **131 N Max** | 3.42 | 0.35 | 3.77 | 42.76 | 0.41 | 3.39 | 0.54 | 1.49 | 0.08 |
| **131 Min** | 2.96 | 0.28 | 3.24 | 41.47 | 0.39 | 2.95 | 0.48 | 1.39 | 0.06 |
| **23/07/2009 - second cut** | | | | | | | | | |
| **131 N Max** | 1.97 | 0.19 | 2.16 | 43.26 | 0.46 | 3.47 | 0.37 | 1.30 | 0.06 |
| **131 Min** | 1.15 | 0.08 | 1.27 | 41.89 | 0.39 | 3.33 | 0.26 | 0.69 | 0.04 |
| **22/09/2009 - final cut** | | | | | | | | | |
| **131 N Max** | 1.59 | 0.14 | 1.73 | 44.79 | 0.23 | 3.13 | 0.38 | 1.04 | 0.05 |
| **131 N Min** | 1.03 | 0.02 | 1.12 | 44.10 | 0.20 | 2.22 | 0.31 | 0.77 | 0.04 |

## Mint trials Year 1 - Table A4:

| | %S | µg/g B | µg/g Cu | µg/g Fe | µg/g Mn | µg/g Zn |
|---|---|---|---|---|---|---|
| **WHRI - shoots removed for topping:** | | | | | | |
| **07/07/2009 - first cut** | | | | | | |
| **300 N Max** | 0.36 | 22.02 | 10.70 | 240.50 | 41.89 | 19.54 |
| **300 N Min** | 0.31 | 19.85 | 8.92 | 178.82 | 35.81 | 18.72 |
| **06/08/2009 - second cut** | | | | | | |
| **300 N Max** | 0.29 | 24.82 | 15.35 | 373.38 | 63.21 | 22.45 |
| **300 N Min** | 0.28 | 21.10 | 11.05 | 212.38 | 60.39 | 17.95 |
| **07/10/2009 - final cut** | | | | | | |
| **300 N Max** | 0.26 | 21.01 | 9.23 | 137.32 | 60.92 | 18.65 |
| **300 N Min** | 0.22 | 19.93 | 8.03 | 102.18 | 52.17 | 13.65 |
| **WHRI - Stem bases cut back after topping (final cut only in year 1 at WHRI):** | | | | | | |
| **07/10/2009 - final cut** | | | | | | |
| **300 N Max** | 0.15 | 22.12 | 7.50 | 370.71 | 57.22 | 10.72 |
| **300 N Min** | 0.06 | 11.73 | 5.72 | 95.68 | 15.31 | 5.82 |
| **VP - shoots removed for topping:** | | | | | | |
| **30/06/2009 - first cut** | | | | | | |
| **131 N Max** | 0.42 | 49.55 | 10.76 | 193.58 | 50.38 | 32.05 |
| **131 Min** | 0.30 | 36.22 | 8.84 | 134.30 | 42.72 | 25.35 |
| **23/07/2009 - second cut** | | | | | | |
| **131 N Max** | 0.32 | 24.39 | 11.15 | 143.50 | 63.95 | 25.70 |
| **131 Min** | 0.31 | 20.97 | 9.20 | 111.03 | 45.33 | 24.72 |
| **22/09/2009 - final cut** | | | | | | |
| **131 N Max** | 0.28 | 26.05 | 10.27 | 93.73 | 523.88 | 27.76 |
| **131 Min** | 0.22 | 25.57 | 8.00 | 71.53 | 357.69 | 22.78 |
| **VP - Stem bases cut back after topping:** | | | | | | |
| **30/06/2009 - first cut** | | | | | | |
| **131 N Max** | 0.28 | 41.12 | 11.95 | 353.89 | 61.85 | 27.56 |
| **131 Min** | 0.26 | 31.60 | 11.14 | 287.16 | 50.65 | 24.45 |
| **23/07/2009 - second cut** | | | | | | |
| **131 N Max** | 0.19 | 22.15 | 11.14 | 515.24 | 54.68 | 19.58 |
| **131 Min** | 0.09 | 15.52 | 10.05 | 146.81 | 25.48 | 13.04 |
| **22/09/2009 - final cut** | | | | | | |
| **131 N Max** | 0.21 | 25.60 | 7.61 | 94.91 | 349.86 | 20.15 |
| **131 N Min** | 0.15 | 23.20 | 5.93 | 80.42 | 202.67 | 14.34 |

## Mint trials 2010 – table A5:

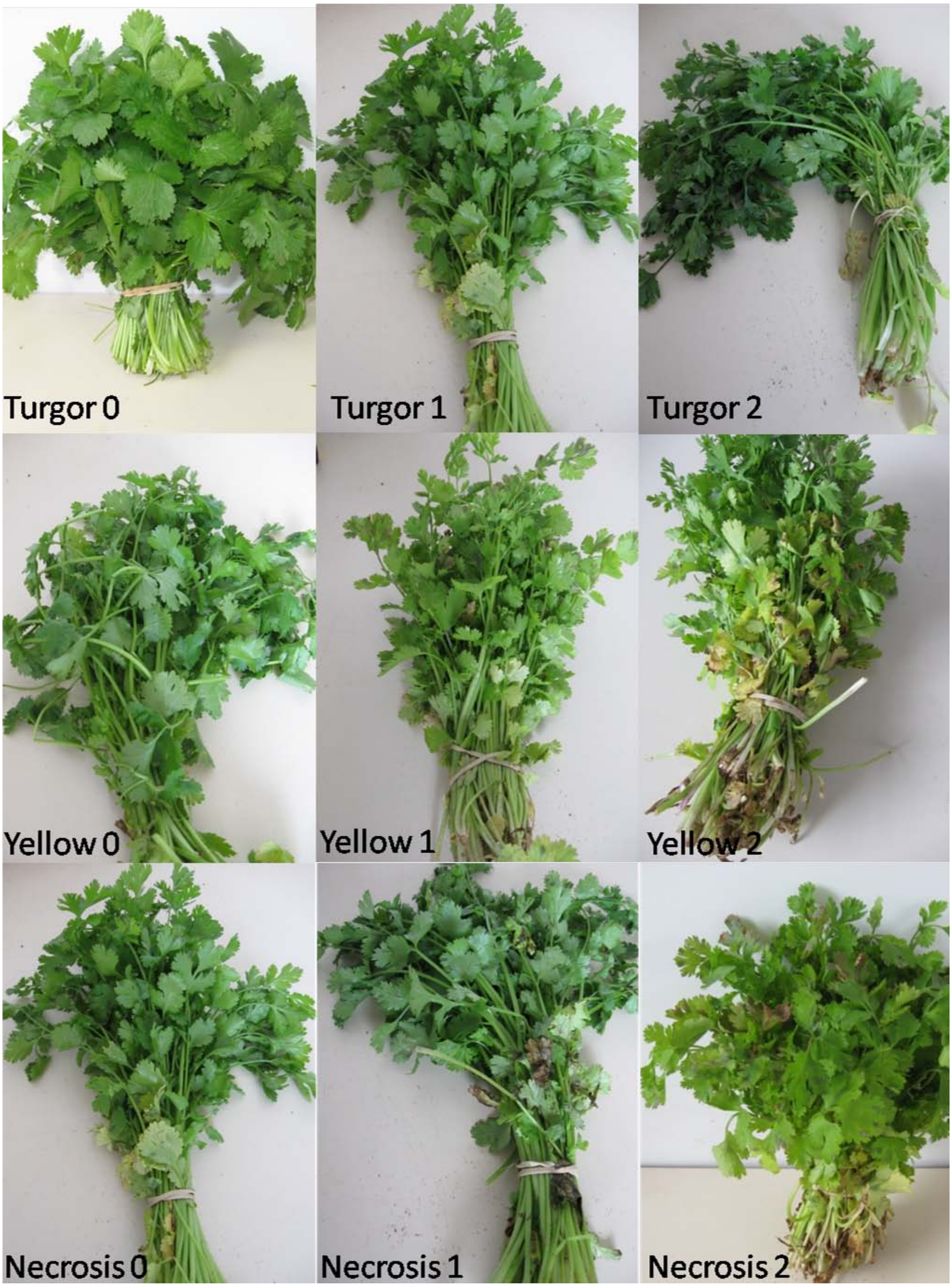
| | % organic N | % min N | % total N | %C | %P | %K | %Mg | %Ca | %Na |
|---|---|---|---|---|---|---|---|---|---|
| **WHRI - shoots removed for topping:** | | | | | | | | | |
| **12/05/2010 - first cut** | | | | | | | | | |
| **300 N Max** | 4.15 | 0.20 | 4.31 | 44.72 | 0.47 | 4.67 | 0.44 | 1.16 | 0.03 |
| **300 N Min** | 3.84 | 0.14 | 3.98 | 44.08 | 0.45 | 4.57 | 0.34 | 1.07 | 0.03 |
| **06/07/2010 - second cut** | | | | | | | | | |
| **300 N Max** | 4.06 | 0.38 | 4.42 | 44.07 | 0.37 | 3.68 | 0.59 | 1.48 | 0.11 |
| **300 N Min** | 3.62 | 0.33 | 3.95 | 43.71 | 0.34 | 3.34 | 0.46 | 1.26 | 0.09 |
| **08/09/2010 - final cut** | | | | | | | | | |
| **160 Max** | 3.44 | 0.43 | 3.85 | 44.39 | 0.43 | 4.38 | 0.43 | 1.27 | 0.09 |
| **160 Min** | 2.78 | 0.37 | 3.15 | 42.79 | 0.36 | 3.89 | 0.30 | 1.01 | 0.06 |
| **WHRI - Stem bases cut back after topping** | | | | | | | | | |
| **12/05/2010 - first cut** | | | | | | | | | |
| **230 Max** | 1.84 | 0.14 | 1.97 | 44.39 | 0.33 | 3.95 | 0.17 | 0.70 | 0.16 |
| **230 Min** | 1.35 | 0.10 | 1.49 | 43.09 | 0.24 | 3.08 | 0.13 | 0.50 | 0.10 |
| **06/07/2010 - second cut** | | | | | | | | | |
| **110 Max** | 1.23 | 0.06 | 1.30 | 43.80 | 0.36 | 3.81 | 0.26 | 0.90 | 0.26 |
| **110 Min** | 1.02 | 0.03 | 1.05 | 42.36 | 0.35 | 3.36 | 0.18 | 0.70 | 0.23 |
| **08/09/2010 - final cut** | | | | | | | | | |
| **110 Max** | 0.98 | 0.22 | 1.16 | 43.84 | 0.40 | 3.70 | 0.16 | 0.61 | 0.33 |
| **110 Min** | 0.74 | 0.08 | 0.82 | 43.28 | 0.33 | 3.26 | 0.15 | 0.53 | 0.30 |
| **VP - shoots removed for topping:** | | | | | | | | | |
| **11/05/2010 - first cut** | | | | | | | | | |
| **380 Max** | 4.61 | 0.08 | 4.69 | 45.09 | 0.53 | 5.16 | 0.48 | 1.42 | 0.05 |
| **380 Min** | 3.72 | 0.02 | 3.74 | 43.73 | 0.46 | 4.57 | 0.44 | 1.19 | 0.04 |
| **07/07/2010 - second cut** | | | | | | | | | |
| **380 Max** | 2.98 | 0.01 | 2.98 | 45.98 | 0.38 | 3.61 | 0.45 | 1.41 | 0.11 |
| **380 Min** | 2.94 | 0.01 | 2.95 | 44.46 | 0.37 | 3.11 | 0.43 | 1.18 | 0.09 |
| **07/09/2010 - final cut - tops already harvested by VP** | | | | | | | | | |
| **VP - Stem bases cut back after topping:** | | | | | | | | | |
| **11/05/2010 - first cut** | | | | | | | | | |
| **380 Max** | 2.88 | 0.18 | 3.06 | 43.33 | 0.35 | 4.29 | 0.30 | 0.96 | 0.10 |
| **380 Min** | 2.05 | 0.03 | 2.08 | 43.05 | 0.30 | 3.95 | 0.26 | 0.94 | 0.06 |
| **07/07/2010 - second cut** | | | | | | | | | |
| **380 Max** | 2.14 | 0.03 | 2.16 | 44.04 | 0.31 | 4.20 | 0.40 | 1.29 | 0.16 |
| **380 Min** | 1.35 | 0.01 | 1.38 | 42.48 | 0.28 | 3.30 | 0.23 | 0.78 | 0.12 |
| **07/09/2010 - final cut** | | | | | | | | | |
| **380 Max** | 1.63 | 0.36 | 1.99 | 43.07 | 0.38 | 4.07 | 0.24 | 0.74 | 0.15 |
| **380 Min** | 1.29 | 0.12 | 1.40 | 42.60 | 0.34 | 3.87 | 0.22 | 0.61 | 0.11 |

### Mint trials 2010 Table A6:

| | %S | µg/g B | µg/g Cu | µg/g Fe | µg/g Mn | µg/g Zn |
|---|---|---|---|---|---|---|
| **WHRI - shoots removed for topping:** | | | | | | |
| **12/05/2010 - first cut** | | | | | | |
| **300 Max** | 0.18 | 23.57 | 8.43 | 158.82 | 130.95 | 25.87 |
| **300 Min** | 0.17 | 21.45 | 7.57 | 118.25 | 105.59 | 22.85 |
| **06/07/2010 - second cut** | | | | | | |
| **300 Max** | 0.38 | 26.53 | 10.05 | 83.58 | 149.94 | 24.98 |
| **300 Min** | 0.33 | 22.61 | 9.05 | 78.72 | 130.76 | 24.58 |
| **08/09/2010 - final cut** | | | | | | |
| **160 Max** | 0.29 | 24.20 | 10.92 | 89.68 | 140.23 | 23.10 |
| **160 Min** | 0.23 | 21.89 | 9.41 | 80.49 | 98.24 | 19.80 |
| **WHRI - Stem bases cut back after topping** | | | | | | |
| **12/05/2010 - first cut** | | | | | | |
| **230 Max** | 0.06 | 14.10 | 6.09 | 78.18 | 47.13 | 9.48 |
| **230 Min** | 0.05 | 11.11 | 4.33 | 52.09 | 33.88 | 7.02 |
| **06/07/2010 - second cut** | | | | | | |
| **110 Max** | 0.14 | 16.75 | 8.64 | 53.67 | 40.39 | 10.63 |
| **110 Min** | 0.11 | 13.20 | 8.08 | 37.65 | 28.36 | 9.41 |
| **08/09/2010 - final cut** | | | | | | |
| **110 Max** | 0.09 | 13.75 | 9.39 | 55.13 | 26.52 | 9.47 |
| **110 Min** | 0.08 | 12.57 | 8.11 | 34.49 | 21.75 | 8.20 |
| **VP - shoots removed for topping:** | | | | | | |
| **11/05/2010 - first cut** | | | | | | |
| **380 Max** | 0.38 | 24.07 | 10.49 | 117.27 | 351.43 | 44.40 |
| **380 Min** | 0.35 | 22.26 | 8.77 | 102.11 | 322.83 | 39.11 |
| **07/07/2010 - second cut** | | | | | | |
| **380 Max** | 0.40 | 24.43 | 9.91 | 88.02 | 204.32 | 45.82 |
| **380 Min** | 0.35 | 23.21 | 9.61 | 85.68 | 139.43 | 41.56 |
| **07/09/2010 - final cut - tops already harvested by VP** | | | | | | |
| **VP - Stem bases cut back after topping:** | | | | | | |
| **11/05/2010 - first cut** | | | | | | |
| **380 Max** | 0.19 | 19.63 | 8.27 | 173.15 | 151.20 | 31.42 |
| **380 Min** | 0.18 | 17.45 | 7.07 | 146.64 | 139.66 | 27.30 |
| **07/07/2010 - second cut** | | | | | | |
| **380 Max** | 0.30 | 23.87 | 7.54 | 97.18 | 170.12 | 38.85 |
| **380 Min** | 0.16 | 17.38 | 6.41 | 57.63 | 125.93 | 28.85 |
| **07/09/2010 - final cut** | | | | | | |
| **380 Max** | 0.15 | 14.97 | 8.48 | 102.21 | 53.86 | 18.30 |
| **380 Min** | 0.12 | 13.44 | 6.19 | 49.52 | 30.88 | 12.95 |

**Appendix 2.**

Standards applied to the qualitative scoring system used in shelf life for coriander



Standards used in the qualitative scoring system for shelf life for mint (bunches failed on necrosis before other scores had developed beyond minor incidence only (i.e. score 0/1).